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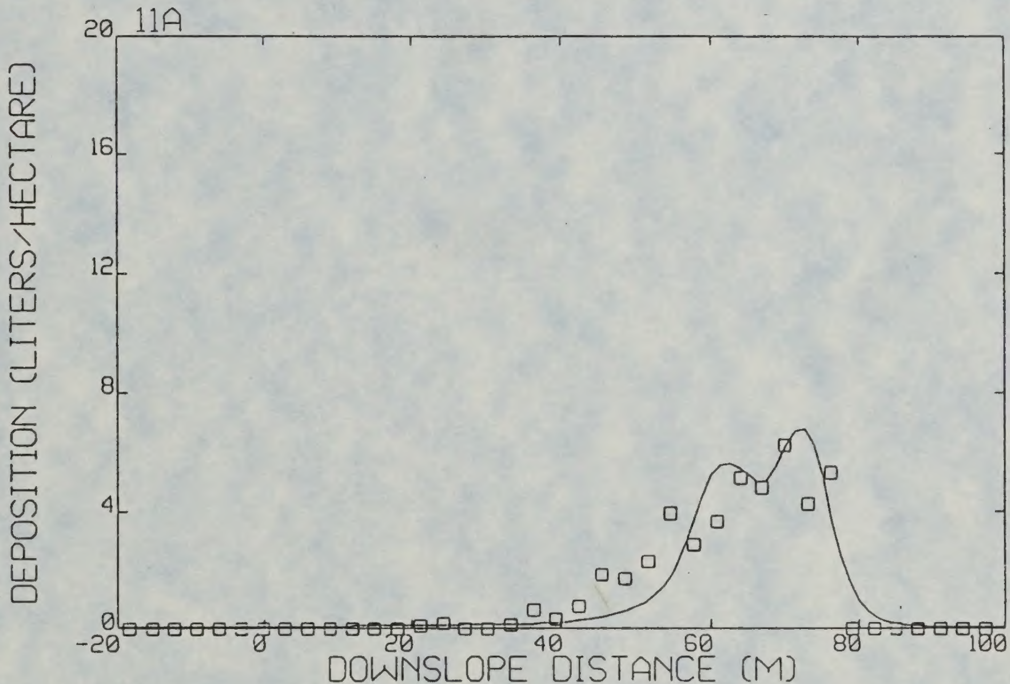
An Examination of AGDISP Helicopter Model Comparisons with Data and Detailed Helicopter Code Predicitions



PROGRAM WIND
COOPERATIVE ATMOSPHERIC RESEARCH

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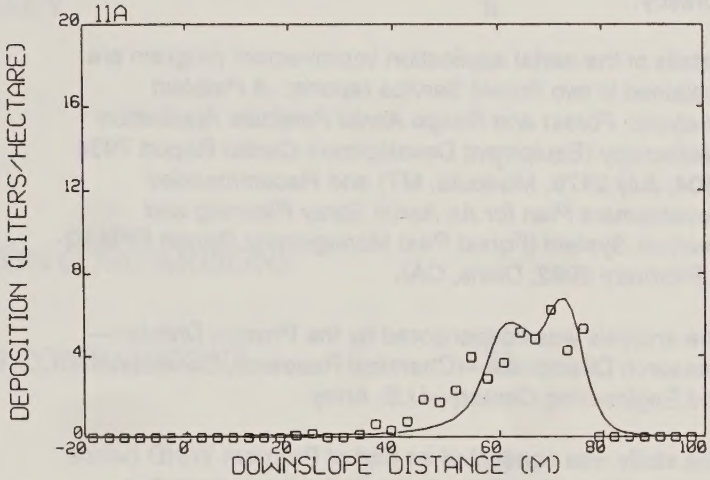
An Examination of AGDISP Helicopter Model Comparisons with Data and Detailed Helicopter Code Predicitions



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(This work was done under contract 53-0343-7-00952)

Pesticide Precautionary Statement

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

Caution: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Foreword

This report is published as a part of the USDA Forest Service program to improve aerial application of pesticides, specifically by using pesticides and delivery systems tailored to the forest environment. The program is conducted jointly by the Technology and Development Center, Missoua, MT , and the Forest Pest Management Staff, Washington Office at Davis,CA, under the sponsorship of State and Private Forestry.

Details of the aerial application improvement program are explained in two Forest Service reports: *A Problem Analysis: Forest and Range Aerial Pesticide Application Technology* (Equipment Development Center Report 7934 2804, July 2979, Missoula, MT) and *Recommended Development Plan for An Aerial Spray Planning and Analysis System* (Forest Pest Management Report FPM 82-2, February 2982, Davis, CA).

The analysis was cosponsored by the Physics Division—Research Directorate—(Chemical Research, Development and Engineering Center)—U.S. Army .

The study was conducted as part of Program WIND (winds in nonuniform domains). Authority for the cooperative program is the Supplemental Agreement, dated February 1985, to the master Memorandum of Understanding Between U.S. Department of Defense and U.S. Department of Agriculture Relative to Cooperation with Respect to Food, Agriculture, and Other Research of Mutual Intesrest.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Ground deposition predictions from the computer program AGDISP are compared with four helicopter trials from Program WIND Phase III (EMCOT). In addition, the simplified downstream wake flow field assumed in AGDISP is compared with a detailed free wake prediction of the trailed helicopter rotor flow field. Results indicate the following:

1. AGDISP does a reasonable job of predicting the shape of the ground deposition pattern in Program WIND.

2. The neutral atmospheric background model in AGDISP should be extended to nonzero Richardson number to modify the ambient turbulence level and improve predicted deposition in stable and unstable layers similar to those present in Program WIND.

3. The Program WIND Phases I and III and Withlacoochee test results should be re-examined now that AGDISP contains a canopy model.

4. Additional tests on flat open terrain with nominal wind speeds are strongly recommended to complete validation of AGDISP helicopter ground deposition predictions.

5. Comparison of the AGDISP helicopter wake flow field model with a more complicated free wake computer model shows excellent agreement between the two models and supports the continued use of the simplified AGDISP model.

1. INTRODUCTION

The computer program AGDISP predicts the motion of aerially released material including the mean position of the material and the position variance about the mean as a result of turbulent fluctuations (Teske, Ref. 1). AGDISP is based on a Lagrangian formulation of the released material equations of motion, and includes simplified models for aircraft wake and ambient turbulence effects. To this point AGDISP predictions have been compared successfully with numerous fixed-wing aircraft data sets (Teske, Ref. 2 for example). Comparisons of the helicopter model have been attempted in the following (Teske, Ref. 3):

1. Forest Service test results from the Withlacoochee seed orchard in 1980 with a Hughes 500C helicopter;

2. Program WIND Phase I test results from the Chico almond orchard in 1985 with a Hiller 12E helicopter; and

3. Program WIND Phase III test results from the Red Bluff forest in 1986 with a Bell 206 helicopter.

These tests were all conducted in a forest canopy; these comparisons were all performed before AGDISP contained a canopy model. Data taken in an open field would remove any canopy influence and provide a clearer data base for AGDISP comparisons. The Program WIND Phase III (EMCOT) data set, collected in open sloping terrain (Ekblad et al., Ref. 4) satisfies many of the requirements for such a study. To this end the four reduced trials (numbers 8, 9, 10 and 11) are compared with AGDISP predictions in Section 2 of this report.

Since its inception, the assumed helicopter wake flow field model in AGDISP has never been compared with data. It appears likely that it never will, since data in close proximity to a helicopter rotor blade is either rare or proprietary. An alternate approach, comparing the assumed AGDISP wake model to the flow field generated by a far more complex (and far more physically detailed) computer model, is examined in Section 3.

The computer program [illegible] the [illegible] and [illegible] ... [illegible] of [illegible] ... [illegible] Ref. [illegible] ... formulation of the [illegible] ... [illegible] ... [illegible] ... (Ref. [illegible]).

1. Phase [illegible] ... Hughes 500 [illegible] helicopter

2. Program WIND [illegible] test results from the [illegible] ... with a Huller [illegible] helicopter

3. Program WIND [illegible] test results from the [illegible] ... Bell 206 helicopter

These [illegible] ... [illegible] ... remove any [illegible] influence and may [illegible] a clearer data base [illegible] ... The [illegible] WIND Phase III [illegible] data set collected [illegible] ... Ref. 4 [illegible] ... [illegible] ...

[illegible] the flow field model [illegible] ... [illegible] that it [illegible] well, since [illegible] ... [illegible] or properties. An [illegible] ... the flow field [illegible] ... [illegible] 3

2. GROUND DEPOSITION COMPARISONS

Program WIND Phase III (EMCOT) Spring Tests were conducted from late April to early May 1986 at a cleared sloping site in the Sierra Nevada foothills approximately 25 miles east of Red Bluff, CA. This area consists of a pair of ridges, between which runs a small stream (Figure 2-1). An anemometer tower grid recorded wake velocities of aircraft traversing normal to the grid. Three card rows were set along the two ridges (Rows A and C) and in the gully at the base of the towers (Row B). Additional meteorological stations around the test site recorded local wind conditions.

All three card rows had a common origin, at A-0, B-0 and C-0, as seen in Figure 2-1. This position is designated 0.0 meters in all that follows. Positive distance is downslope to the west. The aircraft flew north to south along lines parallel to the flight line shown in Figure 2-1. The ground slopes away from the right wing of the aircraft (average downslope is about -3.5 deg).

In all, 49 aircraft flyovers were recorded on the anemometer tower grid (Teske, Ref. 5). Of these runs, 26 flyovers included the collection of ground deposition data along the three card rows. All of this data were subsequently reduced by the USDA Forest Service (R. B. Ekblad, private communication). Analysis of this data and the tests themselves point out the following sources of error:

1. Ekblad et al. (Ref. 4) imply that the assumed spread factor relating card stain size to actual drop size may be in error by up to 20 percent. This suggests that the evaluated mass on the cards could be off by as much as 50 percent.

2. Post-test inspection of the helicopter spray system detected leaks that generated extraneous large drops (above 600 μm), presumably at the expense of smaller drops (below 600 μm).

3. Observations at the test site indicate that the helicopter pilot may have started the spray too late and/or stopped the spray too soon in several of the trials. In these cases the local winds could have drifted the spray beyond a card row before ground deposition.

2. [illegible]

[illegible] Phase II [illegible] in early May [illegible] small stream (Figure 2-1) [illegible]

[illegible] 2-1). The [illegible] shown in [illegible]

In all, 44 aircraft [illegible] were recovered [illegible] Ref. 3). Of these, [illegible] the collection of [illegible] in three card rows. [illegible] subsequently reduced by the [illegible] Service (R. [illegible] Eckel, private communication). Analysis of this [illegible] themselves [illegible] the following sources of error:

1. Lubbick et al. (Ref. 1) imply that the assumed spread factor [illegible] may be [illegible] by up to [illegible] percent. This suggests that [illegible] evaluated mass on the cards could be [illegible] by [illegible] cent.

[illegible] inspection of the helicopter spray system [illegible] (above 600 μm) [illegible]

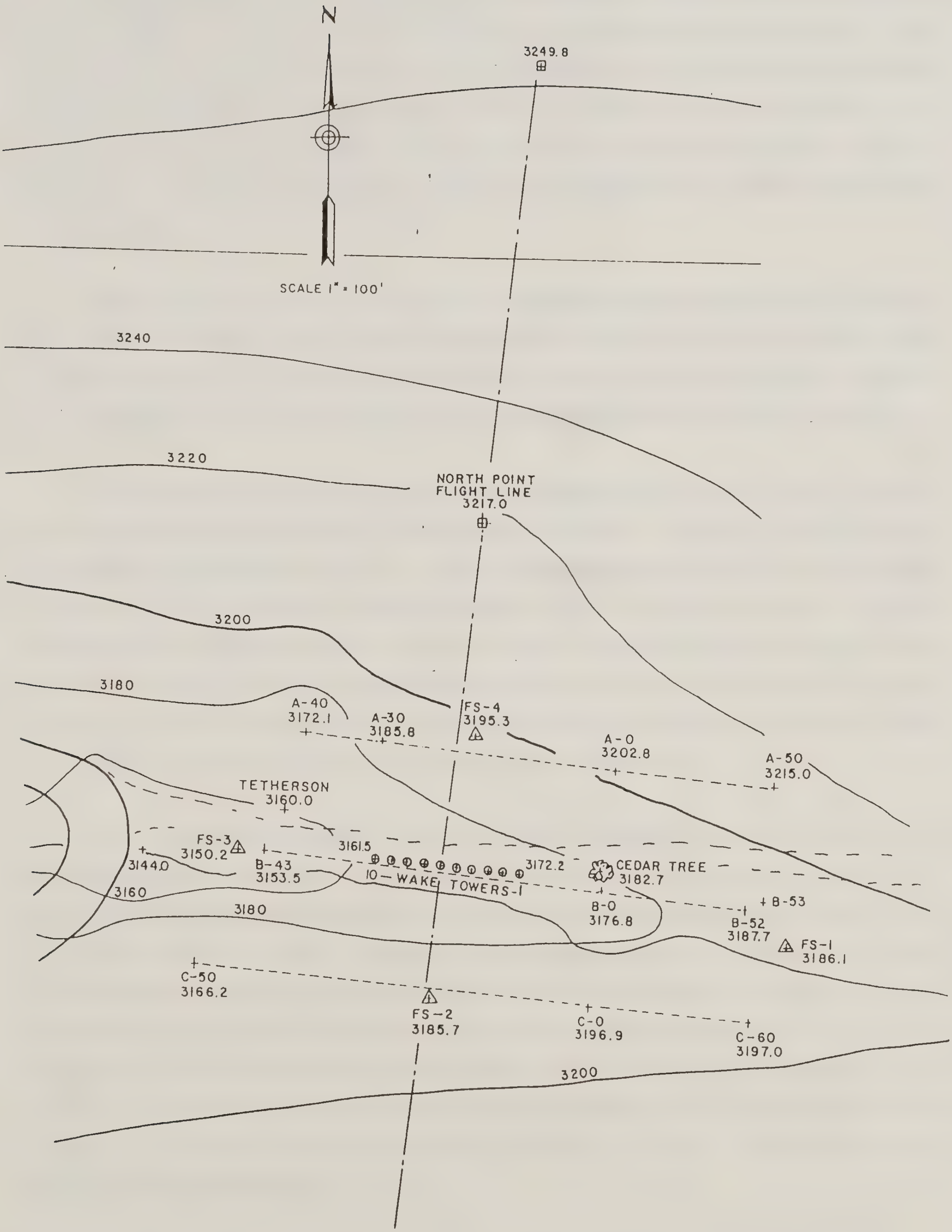


Figure 2-1: Program WIND Phase III (EMCOT) Red Bluff test site.

Integration of the ground deposition pattern from the reduced card data reveals that in many trials, less than one-half of the sprayed material reached the ground. The ambiguity generated by the above three points suggests that any predictions by AGDISP should be normalized by the actual fraction of material recorded on the card rows. This operation makes this test series less than perfect when comparing against AGDISP predictions. Nonetheless, it seems reasonable, since AGDISP will account for all released spray material.

Four trials (numbers 8, 9, 10 and 11) were conducted between 6 and 8:30 am on April 30th. This time period forms the basis for a detailed analysis of meteorological conditions (Hauser et al., Ref. 6) and provides the only trials for which surface winds have been determined. The time-averaged crosswind velocity profiles are shown in Figure 2-2.

AGDISP predictions were made for each of the three card rows for each of the four trials. Helicopter characteristics are summarized in Table 2-1. Specific trial and card row information is presented in Table 2-2. Each AGDISP run combines six drop sizes as given in Table 2-3. The sizes are selected consistent with the card deposition data reduction algorithm (R. B. Ekblad, private communication). The mass fraction for each size was obtained by summing the drop size distribution data from a wind tunnel test of the nozzle and spray material (Yates, Ref. 7). AGDISP comparisons with data are shown in Figures 2-3 to 2-14. A typical AGDISP input deck is shown in Table 2-4.

The "Deposition Fraction" column in Table 2-2 illustrates the material fraction of the 0 to 600 μm drops measured on the cards. Trial 9 Row C is particularly surprising, and highlights the difficulty of using this data set for a definitive comparison with AGDISP predictions. Once AGDISP predictions are multiplied by the "Deposition Fraction," however, the comparisons with data show great similarity for both the Liters per Hectare and the Drops per Square Centimeter deposition plots. The best agreement is Trial 11 Row B in Figure 2-12. The problem with Trial 9 Row C is reflected in the Drop plot in Figure 2-8; a similar problem exists in Trial 10 Row C of Figure 2-11. Most of the rest of the comparisons all show the prediction off to the left of the data. Two reasons may be identified for this discrepancy:

[illegible] plots, less than [illegible] [illegible] the [illegible] ... [illegible] by the [illegible] ... [illegible] [illegible] by AGDISP [illegible] ... [illegible] compared by the [illegible] ... [illegible] ... [illegible] opposite ... [illegible] ... [illegible] conditions. [illegible] ... AGDISP [illegible] ... [illegible] spray material.

[illegible] numbers 9, 10 and 11) [illegible] ... [illegible] and 8.10. At [illegible] ... [illegible] conditions (Haus [illegible], Ref. [illegible]) ... been determined. [illegible] ... [illegible]

AGDISP predictions were made for [illegible] the [illegible] ... trials. Helicopter characteristics [illegible] ... in Table [illegible] ... information is [illegible] ... Figure 2- [illegible] ... in Table 2-3. The [illegible] ... selected [illegible] ... deposition [illegible] ... Bjorklund (R. B. Ekblad, private communication) ... [illegible] by [illegible] ... and [illegible] ... [illegible] and spray [illegible] ... Ref. [illegible] AGDISP comparisons with data are shown in Figures 2-3 to 2-14 [illegible] AGDISP input deck is shown in Table 2-[illegible].

The "Deposition Fraction" column in Table 2-2 illustrates the material amount of the [illegible] ... measured on the cards. Trial 9 [illegible] ... [illegible] and [illegible] the [illegible] ... using this data set for a definitive comparison with AGDISP. [illegible] AGDISP predictions are multiplied by the "Deposition Fraction," however, the comparisons with data [illegible] ... great similarity for both the lateral [illegible] and the [illegible] ... The best agreement is Trial [illegible] ... B in Figure 2-10 [illegible] ... reflected [illegible] ... in Figure [illegible] ... 10 B [illegible] ... 11. Most of the [illegible] ... [illegible] data. [illegible] ... [illegible]

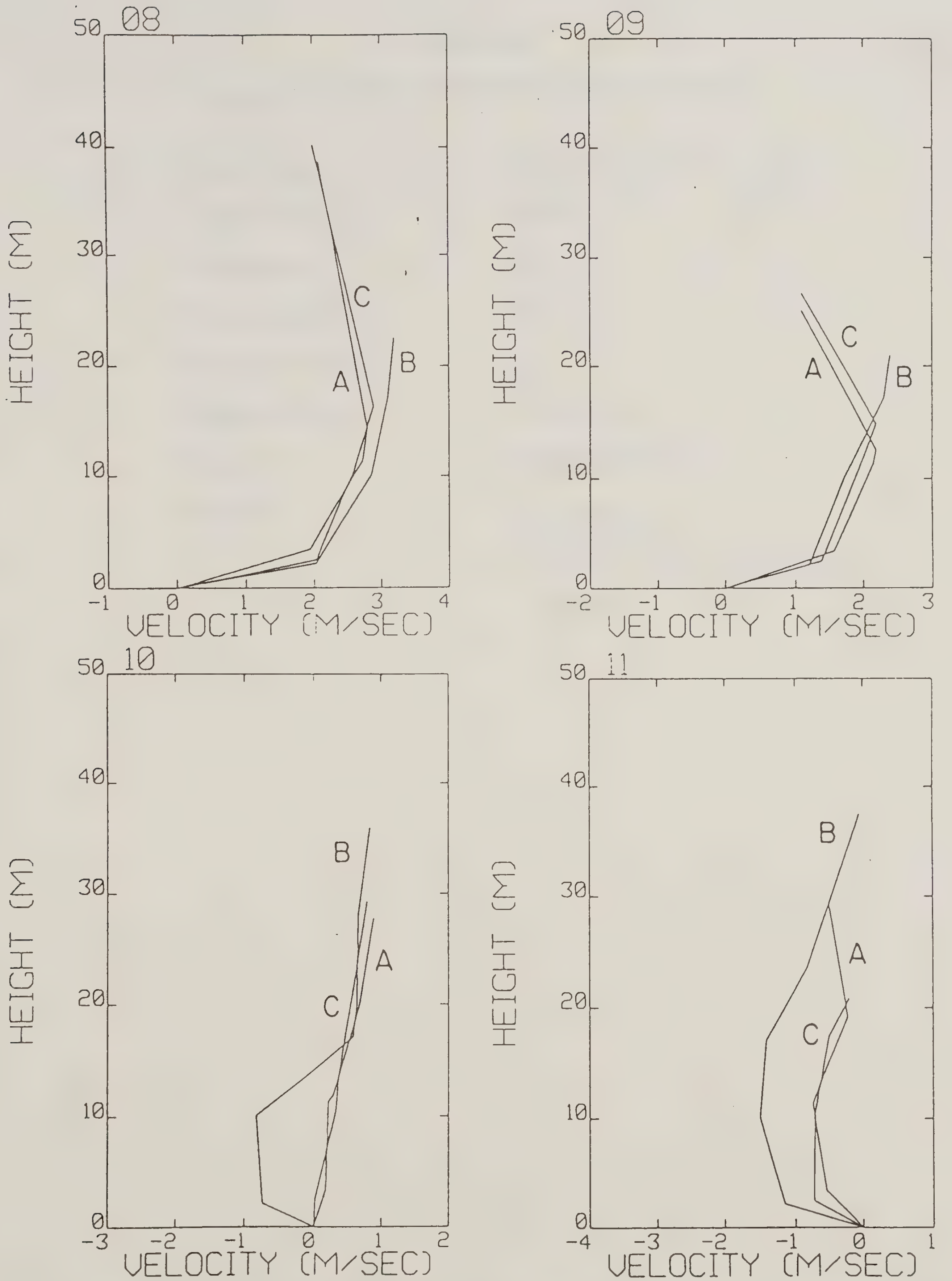


Figure 2-2: Crosswind velocity profiles for card rows A, B and C for trials number 8, 9, 10 and 11.

TABLE 2-1

Program WIND Phase III (EMCOT) Test Characteristics

Aircraft Type	Bell 206 Helicopter
Nominal Weight	9342 N
Rotor Radius	5 m
Blade Rotation Rate	390 rpm
Number of Nozzles	22
Application Rate	19.4 gal/min
Atomizer	D8-45 straight back
Tank Mix	67% water 33% Glycerine 2 lbs/gal No. 2 Blue Food Coloring

TABLE 2-2

Program WIND Phase III (EMCOT) Card Row Characteristics

Trial Number	Card Row	Aircraft Height (m)	Offset Distance (m)	Aircraft Speed (m/sec)	Deposition Fraction
8	A	14.9	51.8	25.0	0.498
	B	22.4	51.8	25.0	0.329
	C	17.0	51.8	25.0	0.447
9	A	13.4	51.8	22.4	0.282
	B	20.9	51.8	22.4	0.289
	C	15.5	51.8	22.4	0.076
10	A	12.7	33.5	20.6	0.354
	B	20.1	33.5	20.6	0.287
	C	14.6	33.5	20.6	0.201
11	A	16.0	70.1	22.4	0.276
	B	23.5	70.1	22.4	0.230
	C	18.1	70.1	22.4	0.206

Aircraft Height (m): Apparent height of the aircraft over the card row at the Offset Distance.

Offset Distance (m): The distance from the zero line (A-0, B-0 or C-0) to the aircraft flight line.

Aircraft Speed (m/sec): The speed of the aircraft.

Deposition Fraction: The mass fraction of material collected on the cards for drop sizes between 0 and 600 μm, divided by the anticipated mass fraction from wind tunnel test data (Yates, Ref. 7) and the application rate.

TABLE 2-3

Program WIND Phase III (EMCOT) Size Distribution Characteristics

Minimum Diameter (μm)	Maximum Diameter (μm)	Average Diameter (μm)	Mass Fraction
0	100	63.0	0.0185
100	200	155.4	0.1029
200	300	253.3	0.1701
300	400	352.4	0.2368
400	500	451.8	0.2132
500	600	551.5	0.1470

Average Diameter (μm): Computed from volume average formula in Herdan (Ref. 8).

Mass Fraction: Summed and interpolated from wind tunnel test data (Yates, Ref. 7).

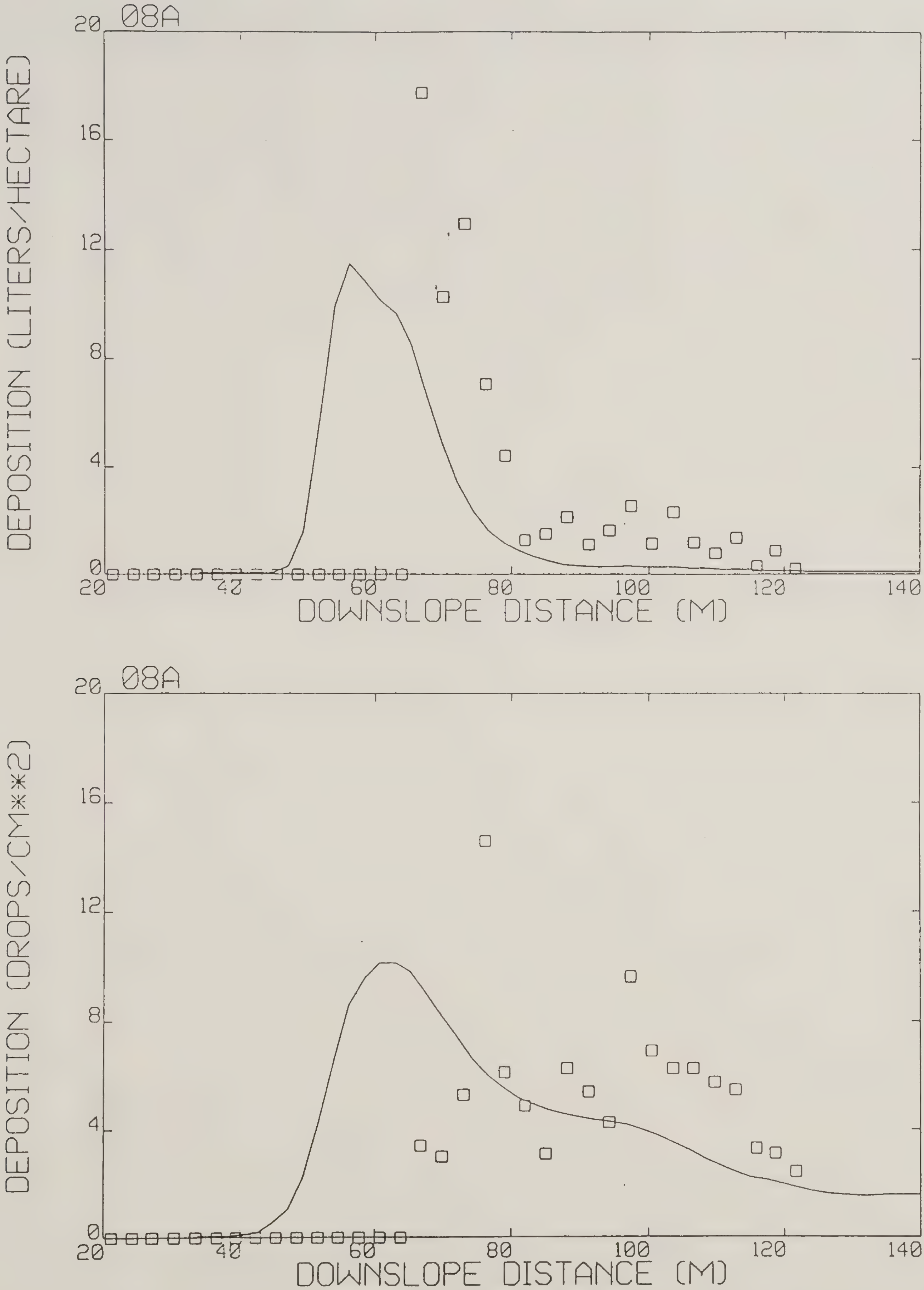


Figure 2-3: AGDISP composite ground deposition predictions (solid curves) compared with card data (squares) for Trial number 8, Row A. The top figure is mass in Liters per Hectare; the bottom figure is number density in Drops per Square Centimeter.

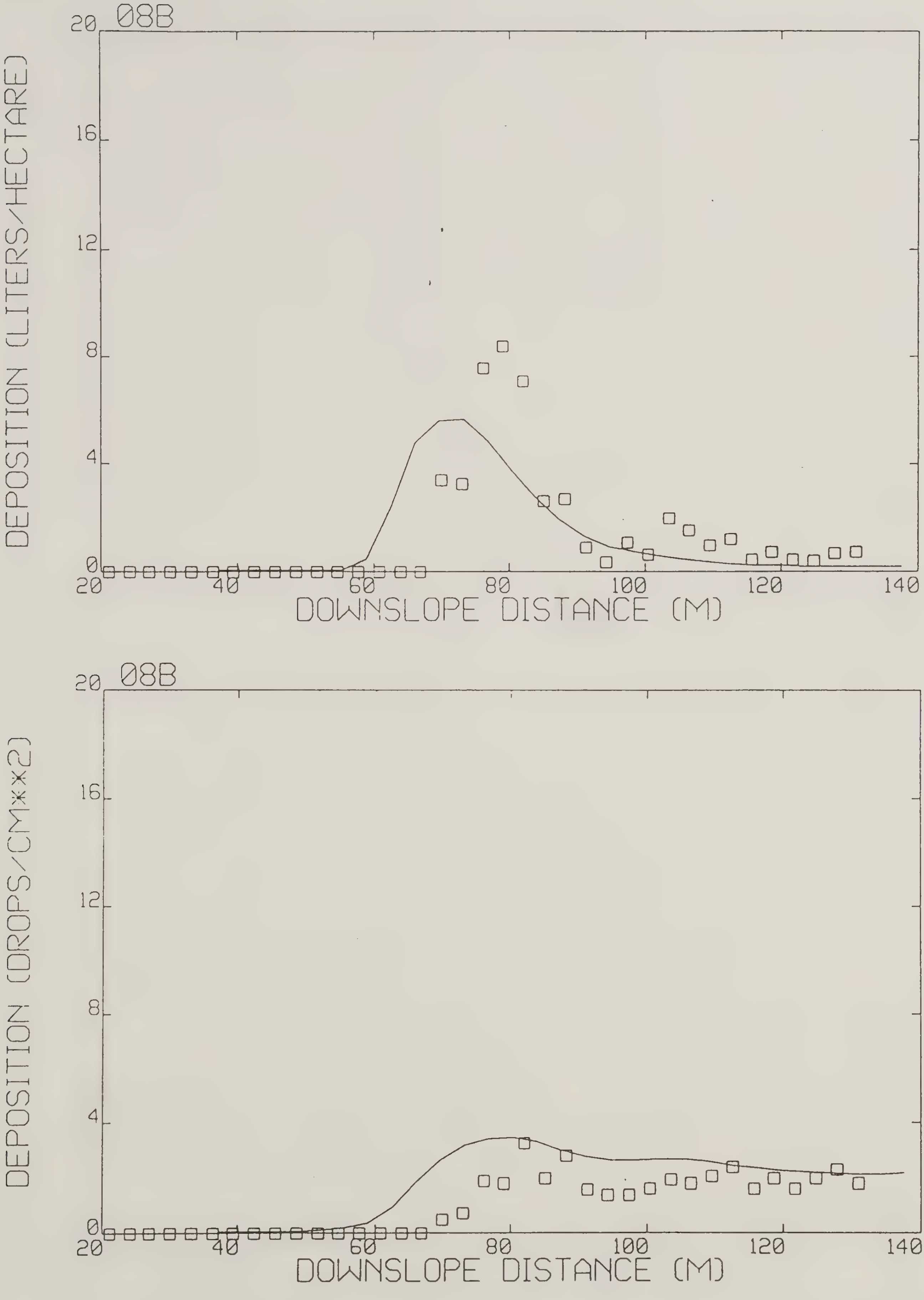


Figure 2-4: Trial number 8, Row B.

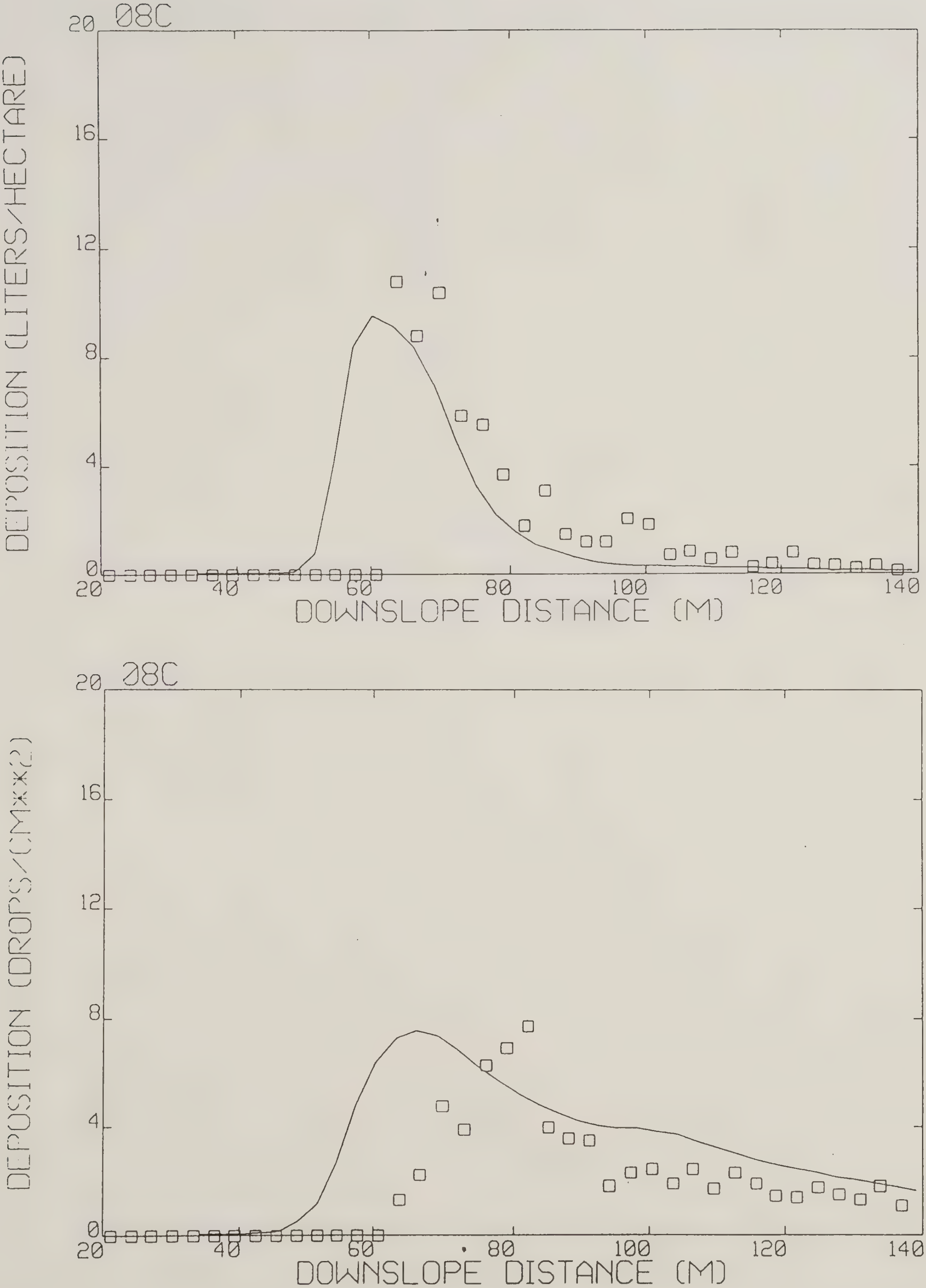


Figure 2-5: Trial number 8, Row C.

[illegible]

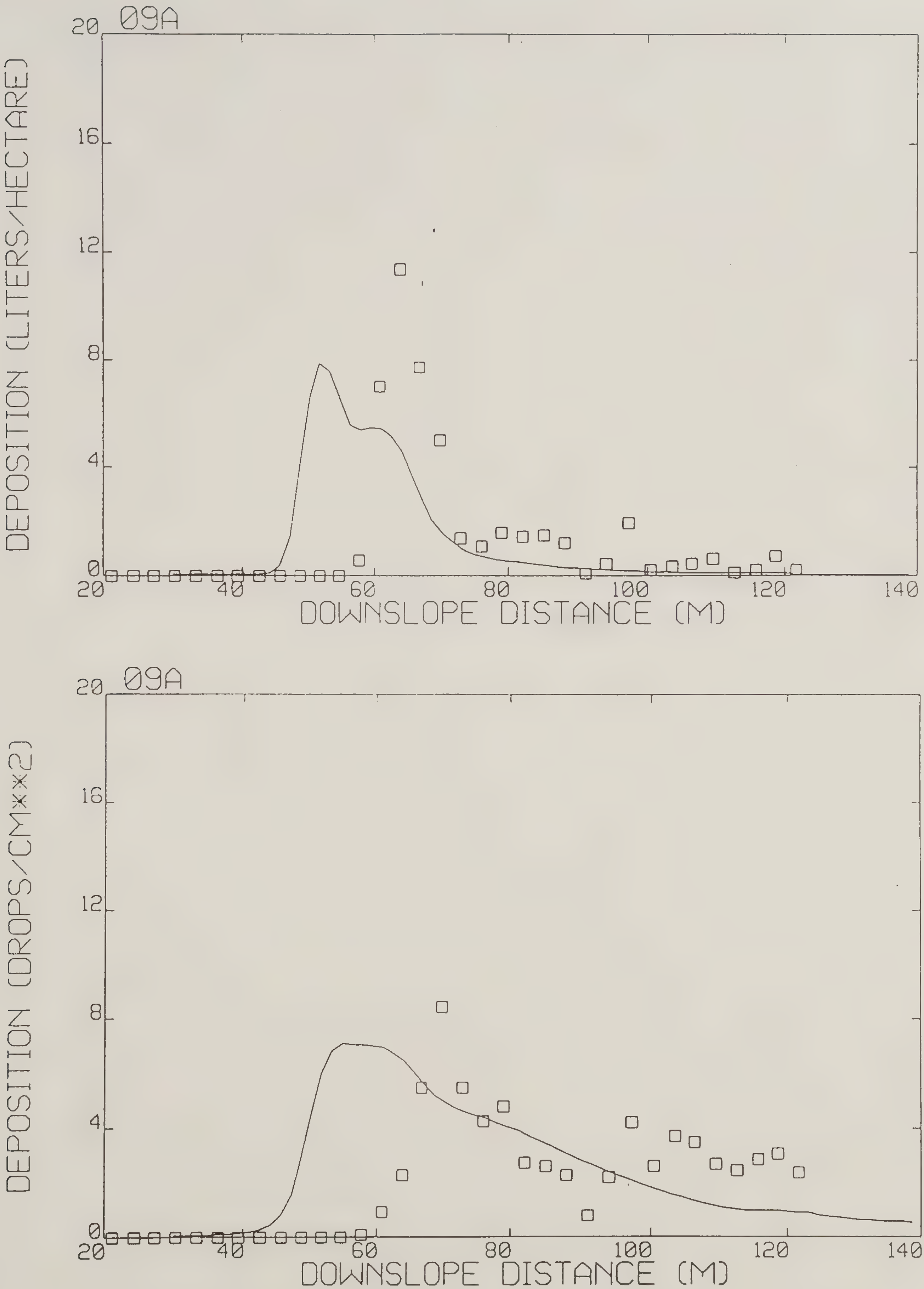


Figure 2-6: Trial number 9, Row A.

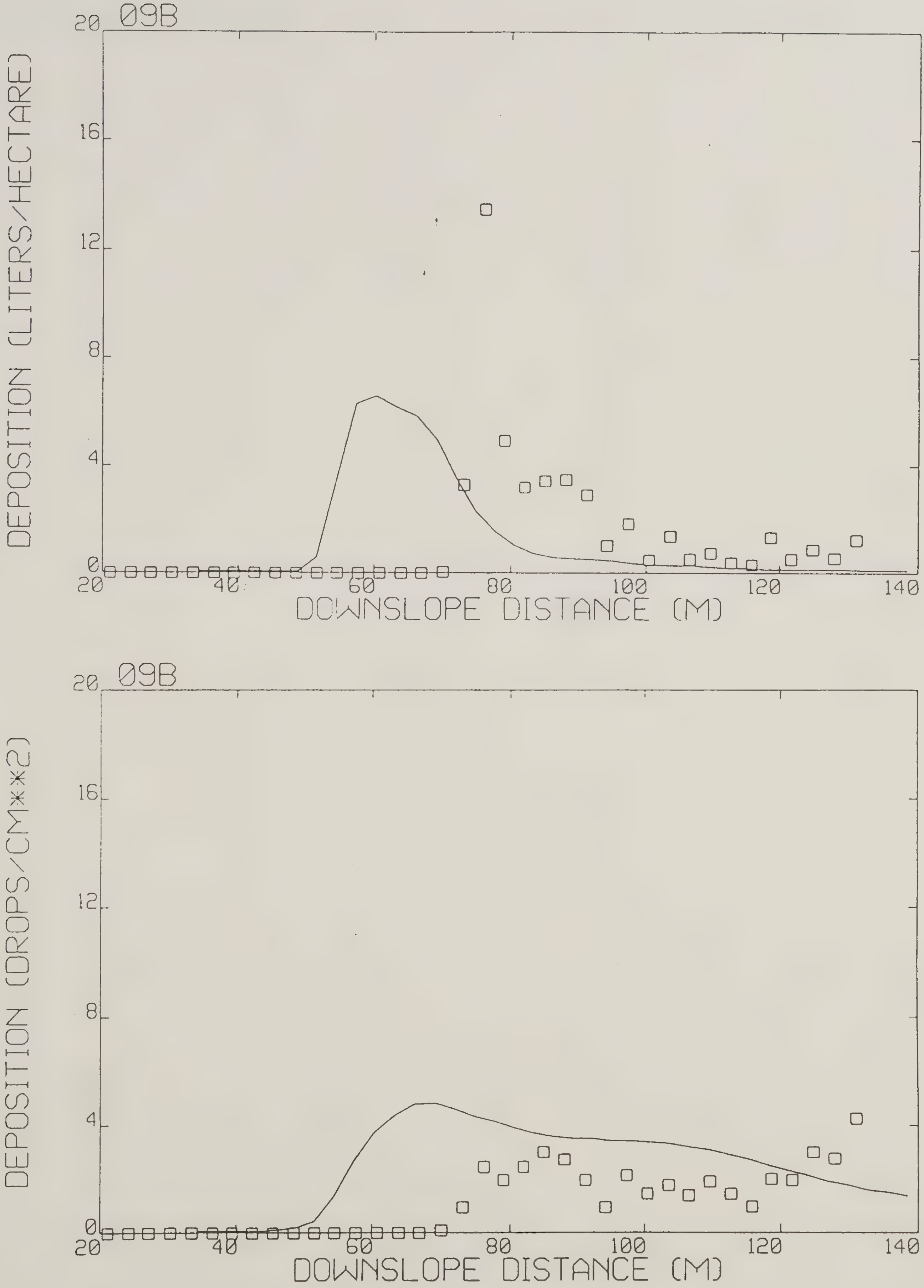


Figure 2-7: Trial number 9, Row B.

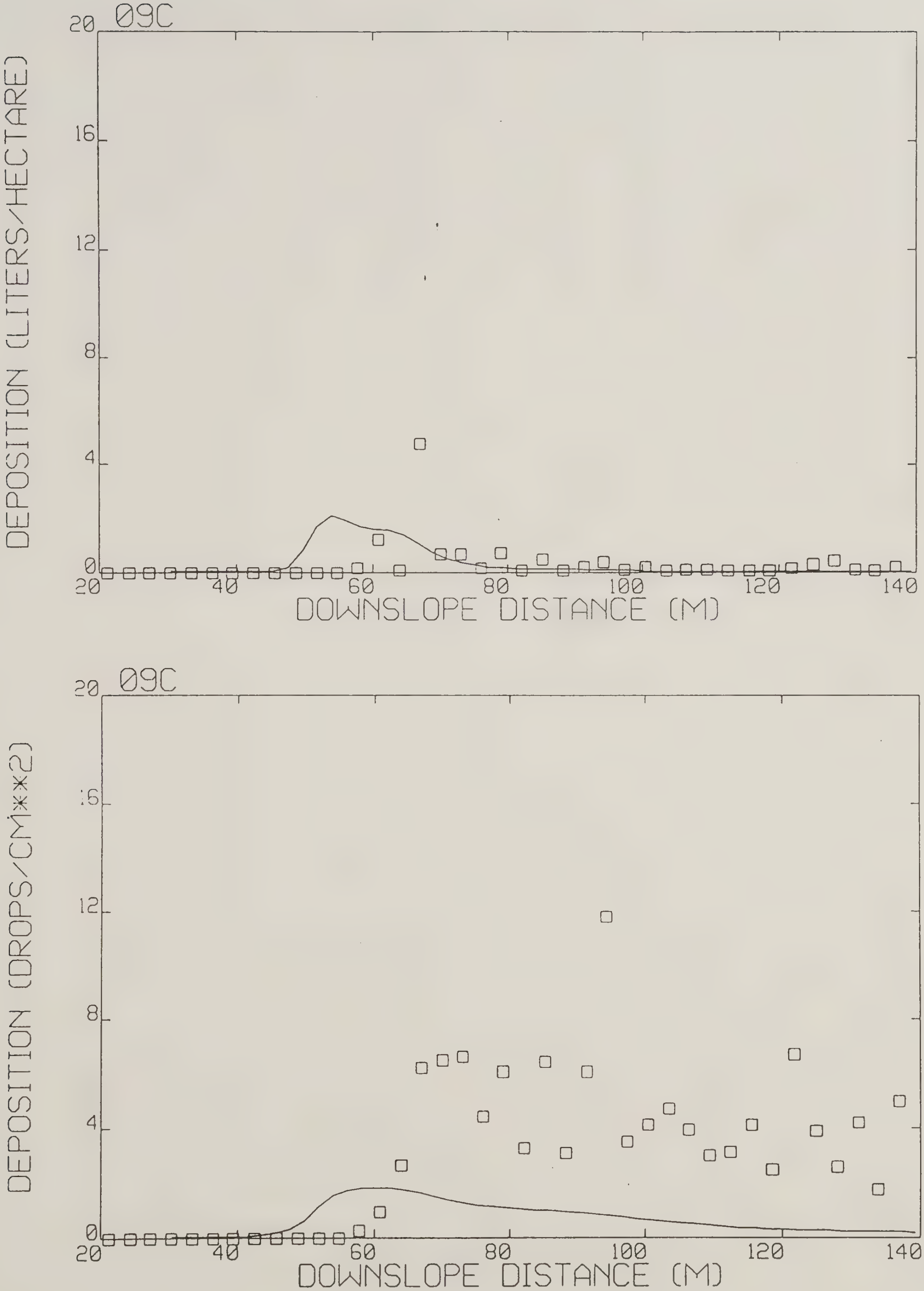
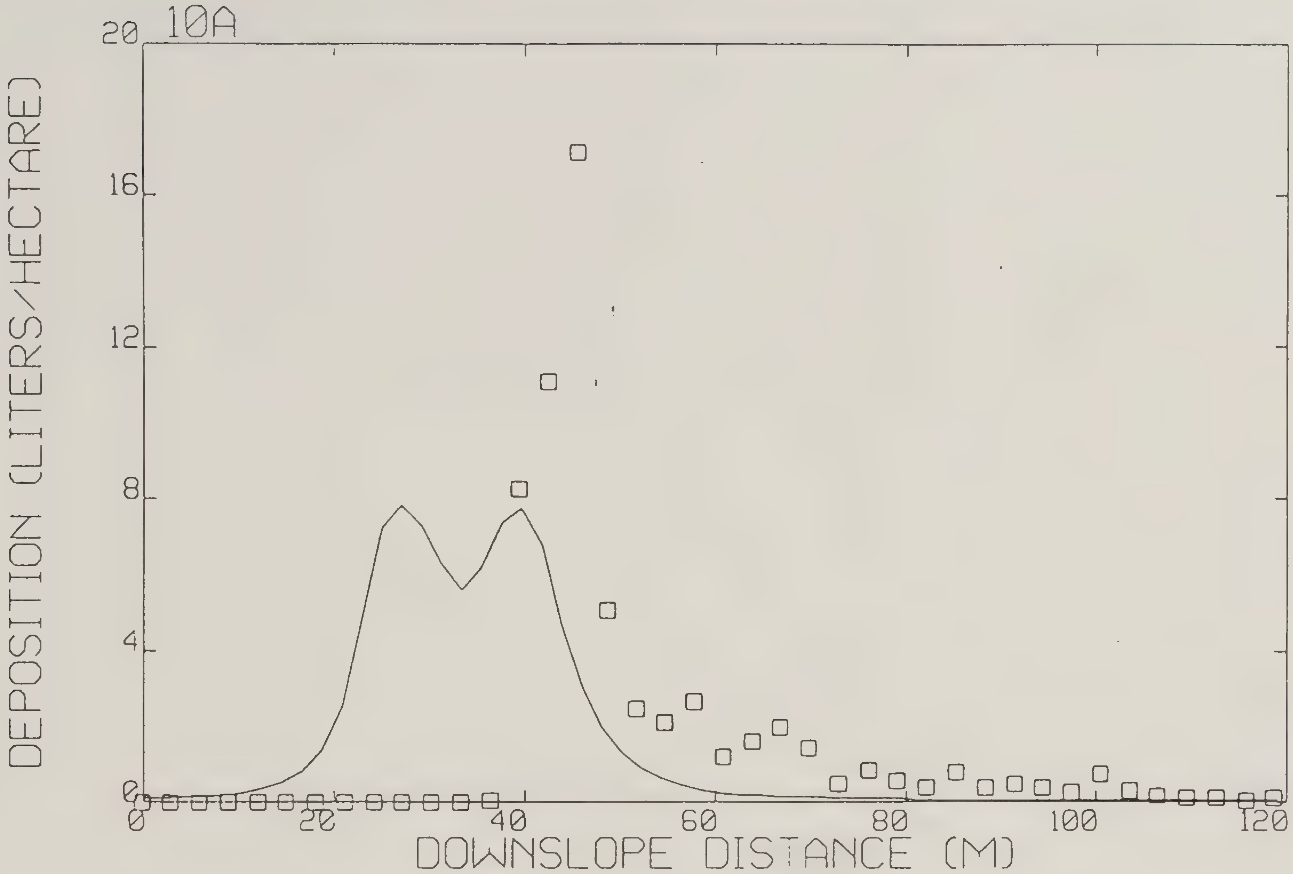


Figure 2-8: Trial number 9, Row C.

[illegible]

[illegible]



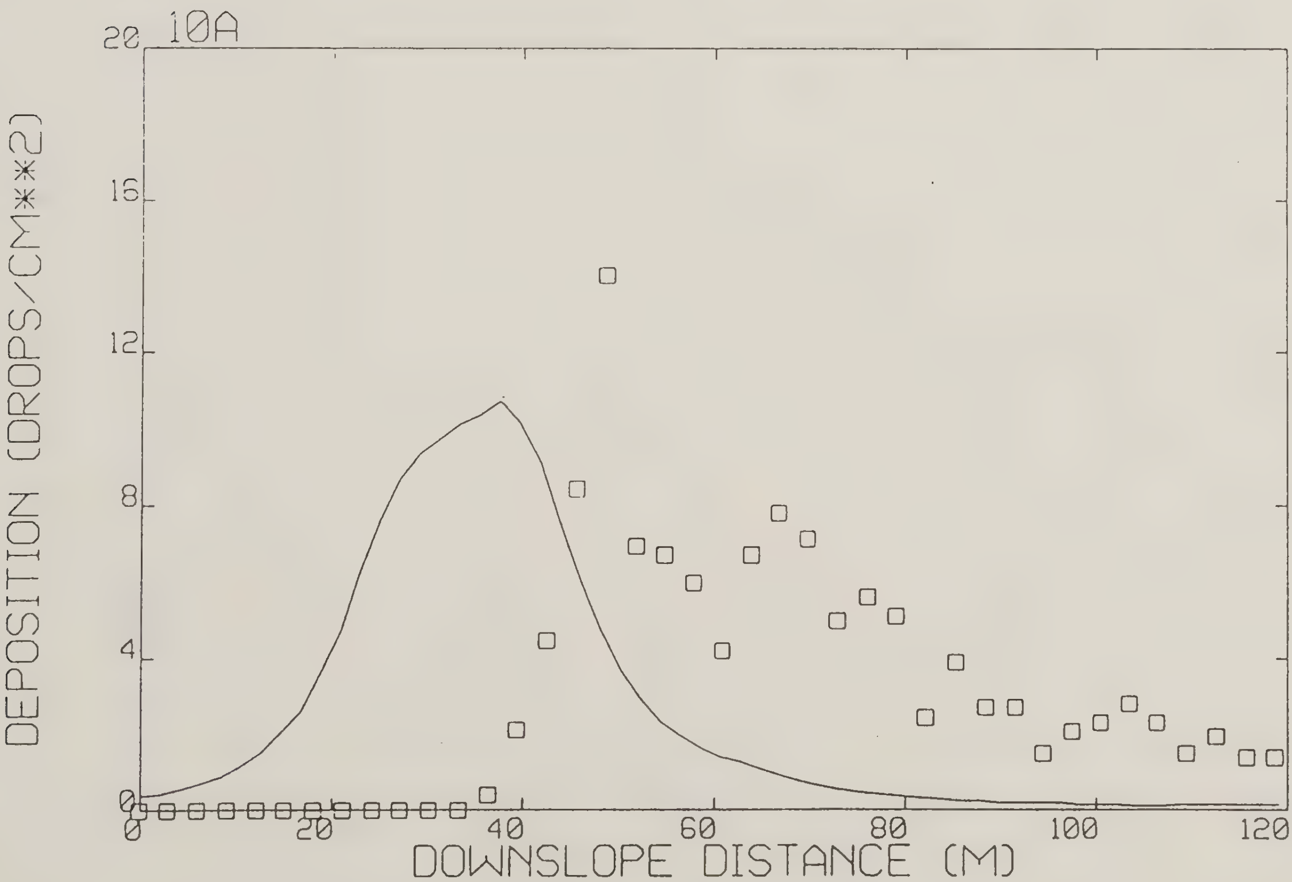
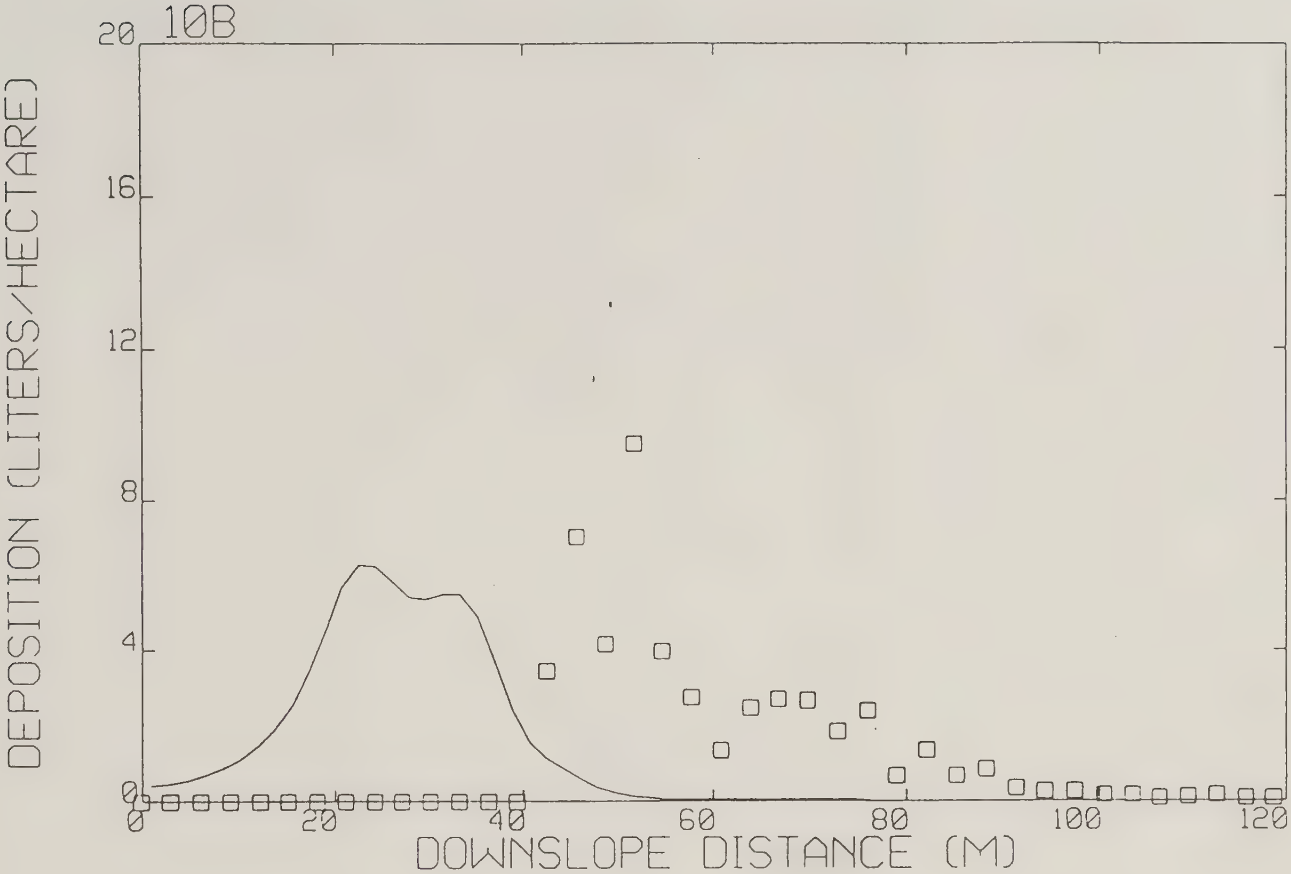


Figure 2-9: Trial number 10, Row A.



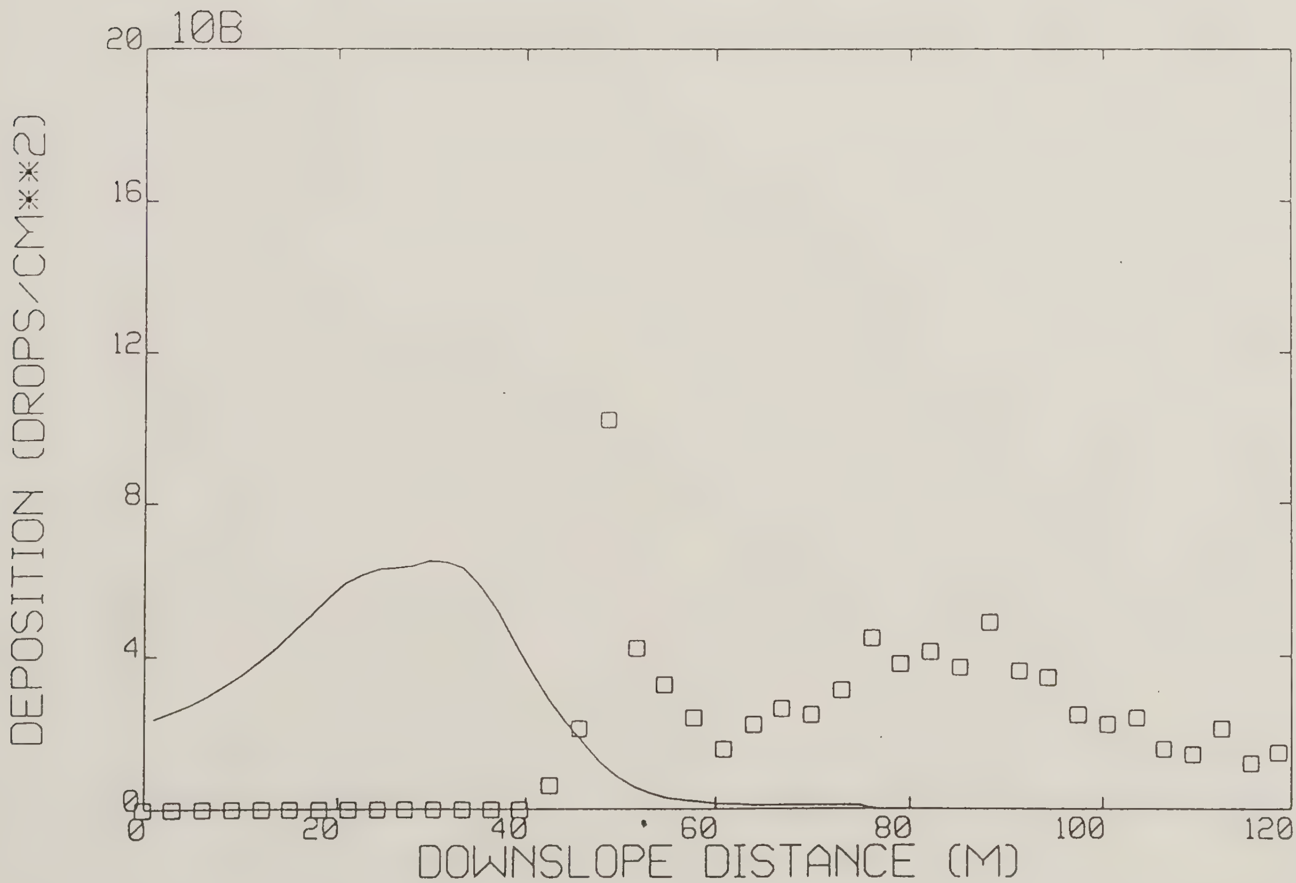
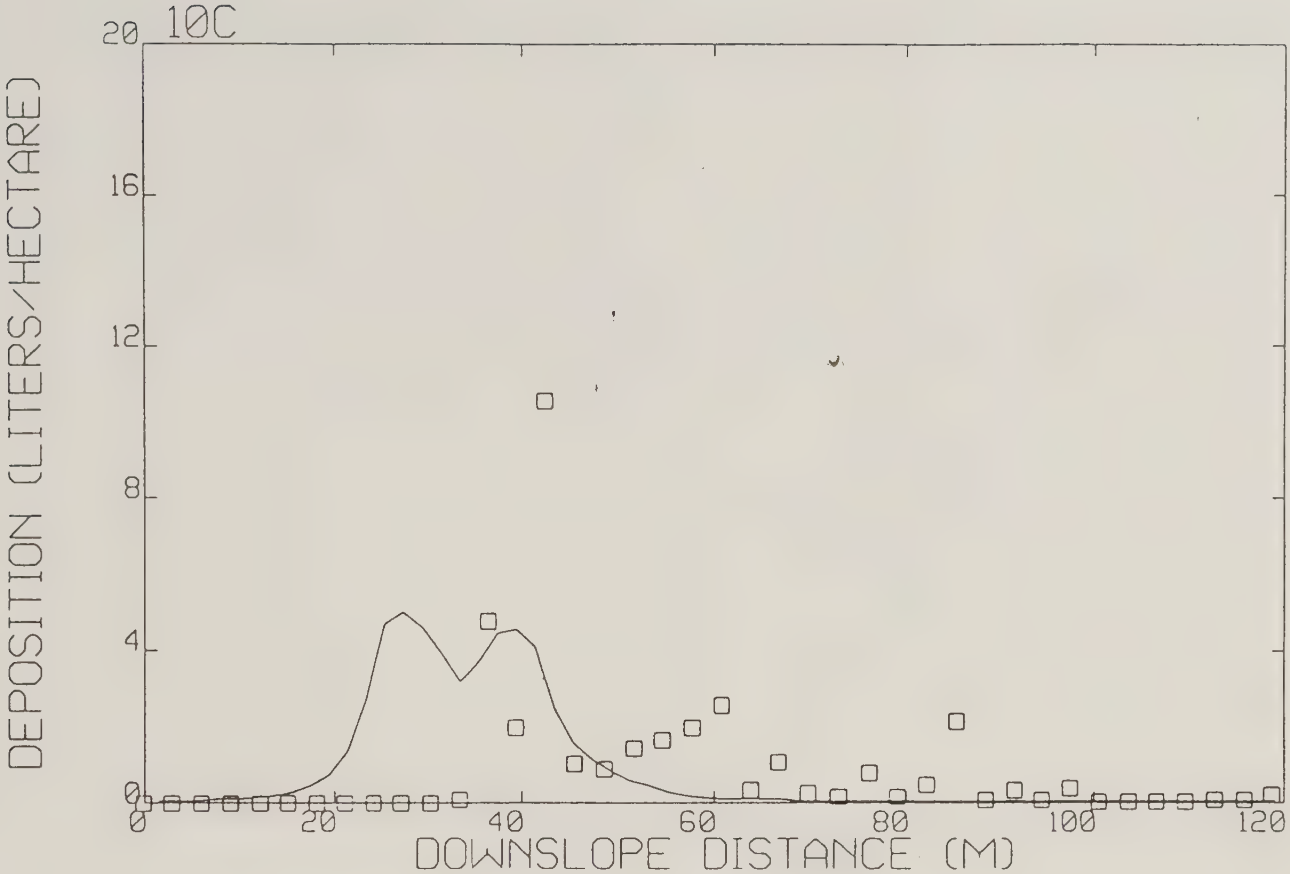


Figure 2-10: Trial number 10, Row B.



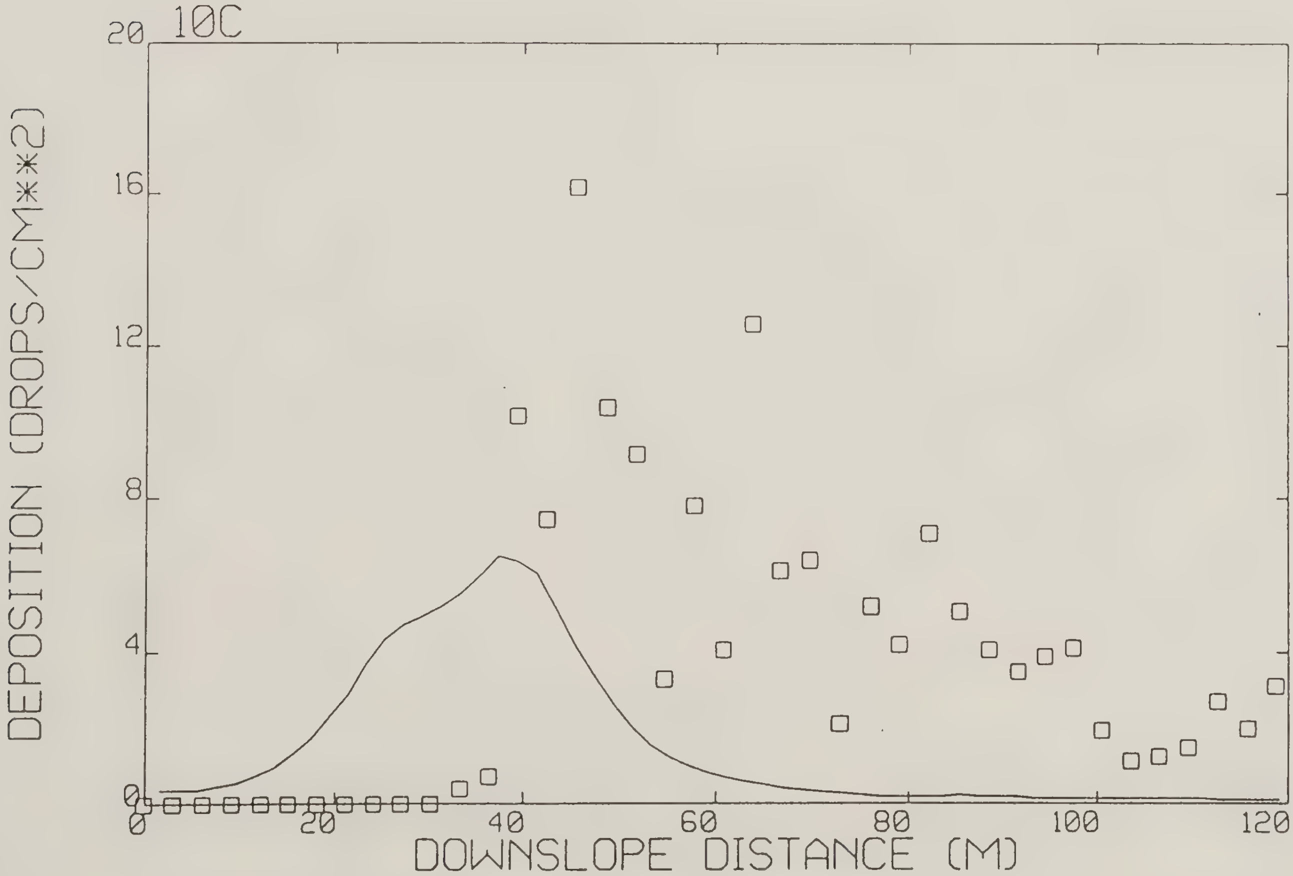


Figure 2-11: Trial number 10, Row C.

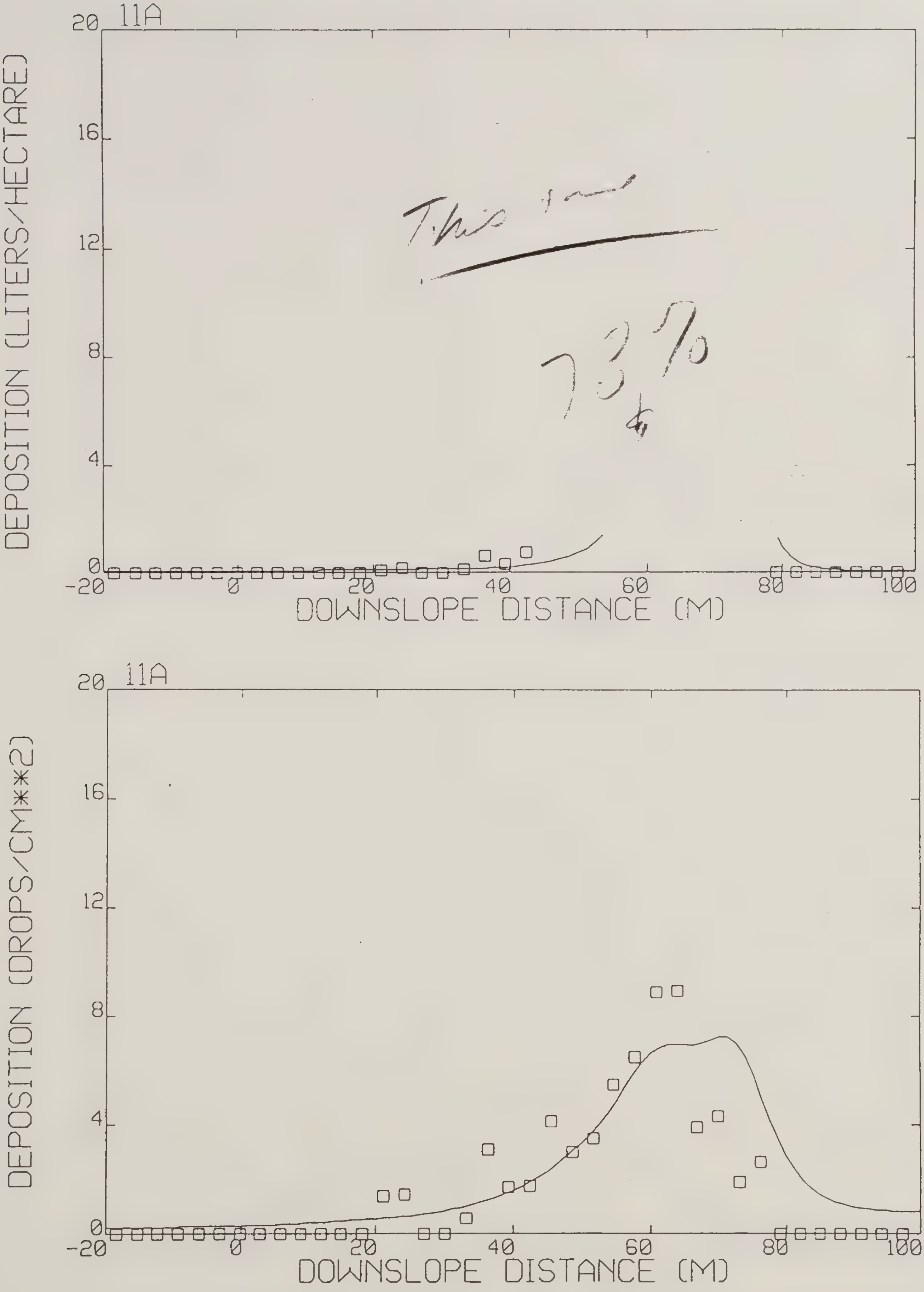


Figure 2-12: Trial number 11, Row A.

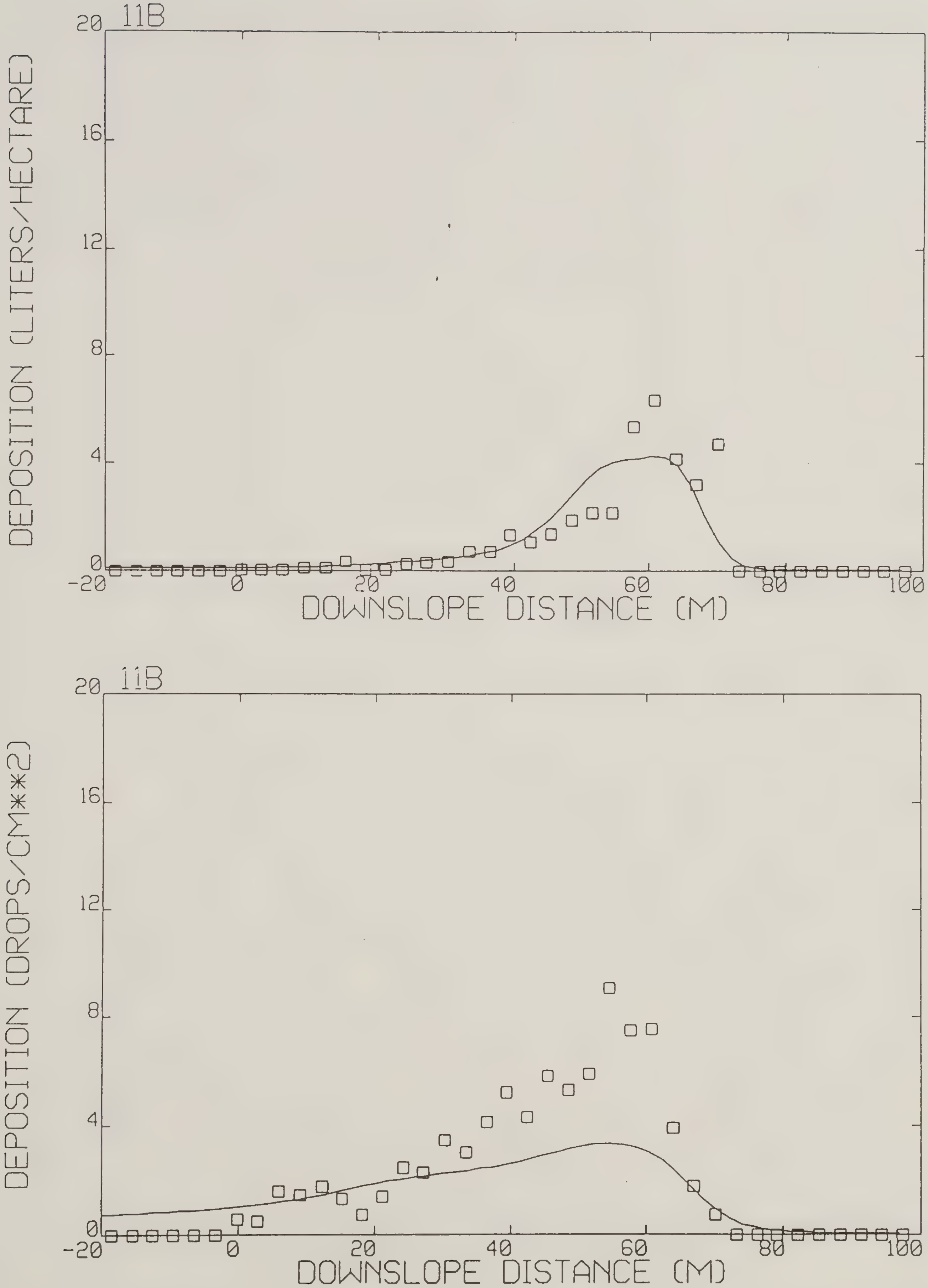


Figure 2-13: Trial number 11, Row B.

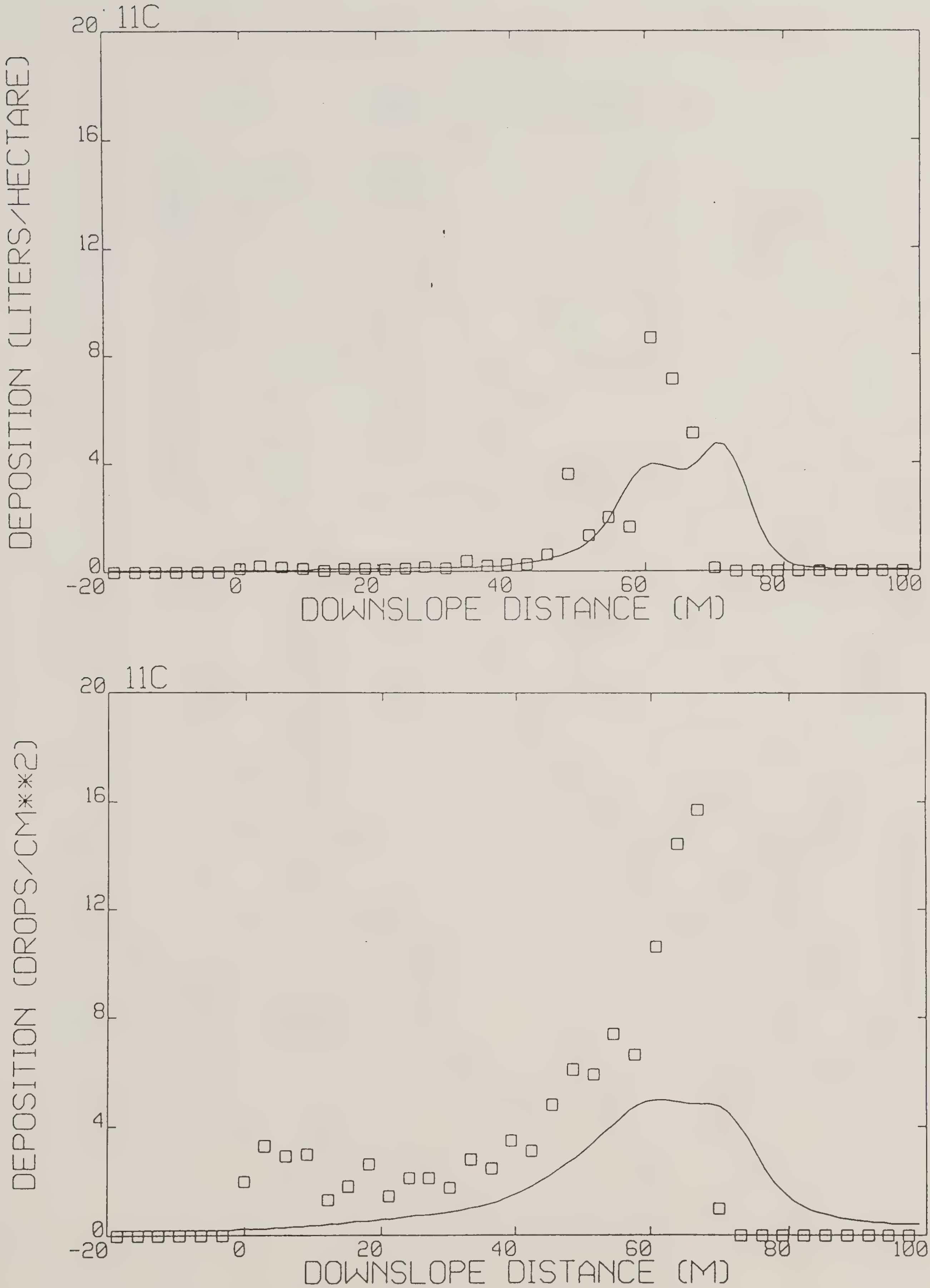


Figure 2-14: Trial number 11, Row C.

TABLE 2-4

Sample AGDISP Input File

```
0000   EMCOT TRIAL 11 LINE B
0010   300.0  2
0011   100  0  0  0
0015   -3.40
0020   4  5.0  23.5  22.4
0029     0.0   0.0    0.0
0029     2.13  0.74  -1.13
0029    10.1   1.45  -1.50
0029    17.1   2.2   -1.4
0029    23.5   2.5   -0.8
0029   -37.5   3.0   -0.05
0030   9342.0  390.0
0050   0  0.0
0060   -11  0  -2.76  0.0  63.0  1.0
0061   -5.03   -2.76
0061   -4.57   -2.76
0061   -4.12   -2.76
0061   -3.66   -2.76
0061   -3.21   -2.76
0061   -2.74   -2.76
0061   -2.29   -2.76
0061   -1.83   -2.76
0061   -1.52   -2.76
0061   -0.914  -2.76
0061   -0.457  -2.76
0061    0.457  -2.76
0061    0.914  -2.76
0061    1.52   -2.76
0061    1.83   -2.76
0061    2.29   -2.76
0061    2.74   -2.76
0061    3.21   -2.76
0061    3.66   -2.76
0061    4.12   -2.76
0061    4.57   -2.76
0061    5.03   -2.76
```

1. The time-averaged crosswind velocity profiles (Figure 2-2) may not faithfully represent the actual winds during deposition. Previous AGDISP comparisons (Teske, Ref. 2) show excellent agreement with ground deposition data when crosswind is present. The crosswind velocity profiles are imposed on the AGDISP trajectory solution; if these profiles are incorrect, AGDISP cannot generate accurate ground deposition plots.

2. The position of the aircraft relative to A-0, B-0, C-0 may be incorrect. Field observations provided this information.

These trials were conducted in the early morning hours when a temperature inversion and accompanying stable boundary layer are generally present. The AGDISP model considers only neutral conditions; the presence of a stable atmosphere would decrease the effect of ambient turbulence on the growth rate of the spread of the released material about the mean material trajectories. Atmospheric stability is a function of the Richardson number, a nondimensional parameter that relates the local temperature gradient to the local velocity gradient (Monin and Yaglom, Ref. 9). Simplified theories of turbulence (Bilanin et al., Ref. 10) may be interpreted to compare the effect of stability on ambient turbulence level. Such a plot is given in Figure 2-15. For the stable conditions of the present study, the anticipated Richardson number would be positive, the "Turbulence Factor" would be less than one, the growth rate of the spread of the released material would be diminished, and the predictions in Figures 2-3 to 2-14 would all exhibit larger, narrower depositions as suggested by the data. The effect of stability on turbulence should be added to the AGDISP computer program, and could possibly be implemented with a stability ratio (SR) approach similar to that suggested by Akesson and Yates (Ref. 11) to characterize ambient atmospheric conditions.

The mass-averaged [illegible] velocity profile [illegible] faithfully represent the actual winds during the trial. [illegible] A1 [illegible] comparisons (Table [illegible] 2) show excellent agreement with [illegible] deposition and when crosswind is present. The [illegible] velocity [illegible] are imposed on the AGDISP trajectory solution; [illegible] measured AGDISP [illegible] average ground deposition plots.

The position of the aircraft relative to A-0. [illegible] C-0 [illegible] is important. [illegible] observations provide this information.

These trials were conducted in the early morning hours when a temperature inversion [illegible] accompanying a stable boundary layer may be present. The AGDISP model assumes only neutral conditions; the presence of a stable atmosphere would decrease the effect of ambient turbulence on the growth rate of the spread of the [illegible] material about the mean centerline [illegible]. Atmospheric stability is a function of the Richardson number, a nondimensional parameter that relates the local temperature gradient to the local velocity gradient (Monin and Yaglom [illegible]). Simplified theories of turbulence (Bilanin et al. [illegible]) may be integrated to compute the effect of stability on ambient turbulence level. [illegible] plot is given in Figure 2-1[illegible] [illegible] of the present study, the anticipated Richardson number would be positive, the "Turbulence Factor" would be less than one, the growth rate of the spread of [illegible] and [illegible] diminished and the predictions in Figures 2-9 to 2-14 would exhibit larger [illegible]. The effect of stability on turbulence should be added [illegible] and could possibly be incorporated with [illegible] stability [illegible] and Yates ([illegible]) to [illegible]

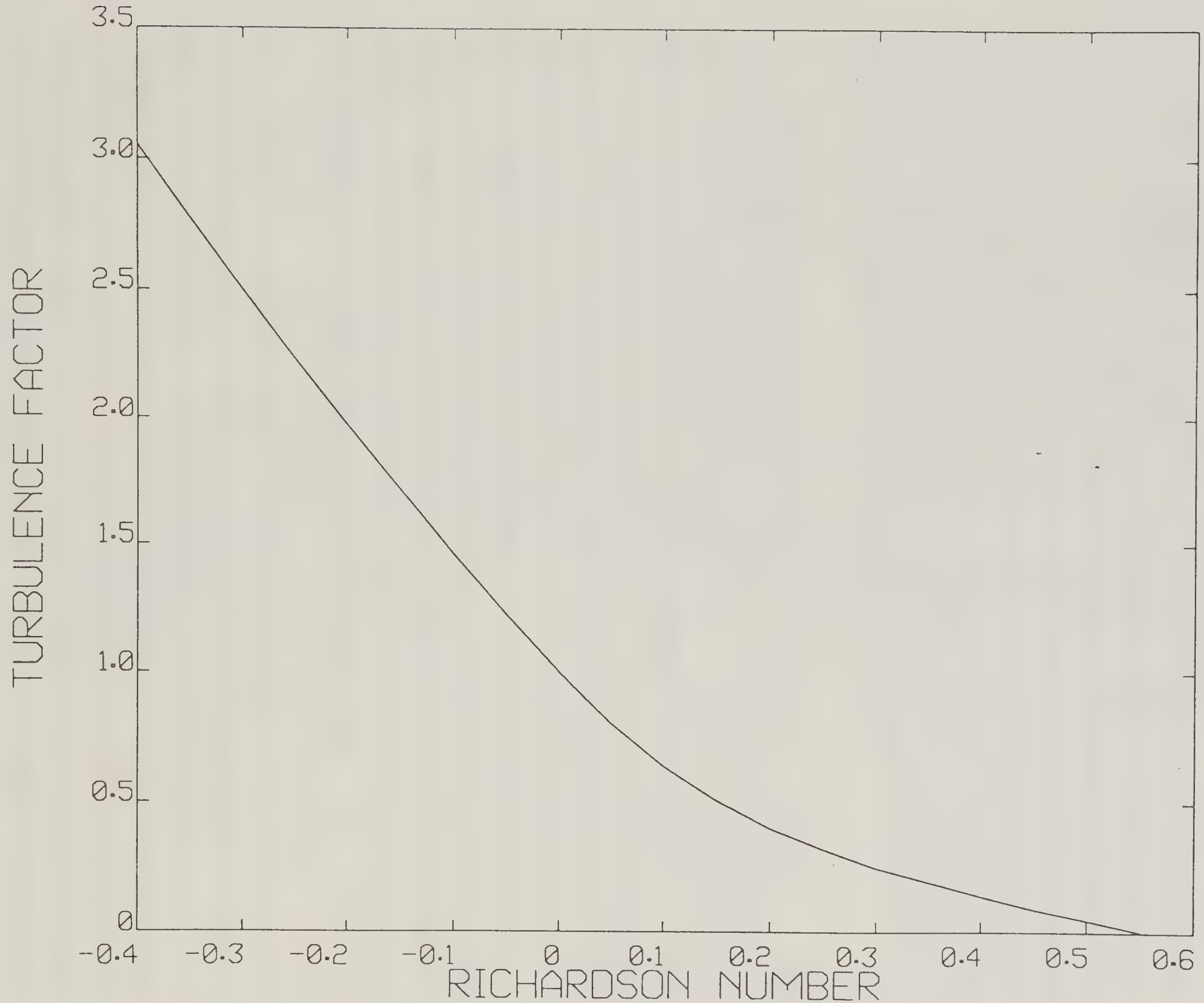


Figure 2-15: Turbulence level in nonneutral atmospheric conditions referenced to neutral (Richardson number = 0). Stable conditions are positive Richardson number; unstable conditions are negative Richardson number. Values are computed from superequilibrium turbulence (Bilanin et al., Ref. 10).

3. WAKE FLOW FIELD COMPARISONS

The helicopter wake flow field model in the AGDISP computer program (Teske, Ref. 1) includes both the hover downwash and the generated tip vortex pair by partitioning the helicopter weight between the two effects as a function of distance downstream. The hover downwash model is taken from actuator disk theory for a propeller, while the strength of the tip vortex pair is found by assuming a rectangularly loaded rotor blade circulation distribution. The partitioning is done by an exponential function F that begins at 0.0 (the wake is all helicopter downwash) and quickly increases in value toward 1.0 (the wake is all vortex pair). A model constant in F was set by comparison with preliminary free wake forward flight code predictions (Bliss et al., Ref. 12).

The simplified AGDISP model for the growth of the tip vortex circulation strength may be compared with predictions from the most detailed (and available) helicopter wake flow field model (Quackenbush and Bliss, Ref. 13). This code utilizes a numerical analysis based on the curved vortex filaments described in Bliss et al. (Ref. 12). The model is composed of vortex filaments laid down along contours of constant sheet strength in the wake. The skewed/curved filaments provide a natural representation of the free wake vorticity field, which simultaneously accounts for both shed and trailed vorticity. An additional advantage of the model is that it provides a visually meaningful representation of the wake since the filaments correspond to the actual resultant vorticity field. Vortex filaments leaving the blades are all of constant strength and equal value. For this reason close spacing between the filaments implies a strong net influence from that region of the wake, whereas a sparse spacing indicates a region having little effect.

Figure 3-1 presents the results of running this computer model for the Bell 206 helicopter conditions given in Table 2-1 previously. Figure 3-1 shows the vortex filament structure trailing off one of the two blades (for clarity). It is quite complicated and, when combined with filaments from the other blade, generates the wake flow field downstream of the helicopter. Crossplane velocity vector plots are shown at one, two and three blade radii downstream in Figures 3-2a, 3-2b and 3-2c respectively, compared against AGDISP helicopter model predictions for the same initial conditions. The familiar vortex-pair-like velocity pattern is very evident. So too is the anticipated lateral asymmetric structure of the downwash flow field in the complicated helicopter model results. The right (advancing blade) side exhibits a somewhat weaker tip vortex than the left (retreating blade) side. At the later radii the mean position of the vortex pair is seen to move downward.

3. WAKE FLOW FIELD COMPARISONS

The helicopter wake flow field model in the AGNESP computer program (Hess, Ref. 1) includes both the hover downwash and the generated tip vortex pair by partitioning the helicopter weight between the two effects as a function of forward speed. The hover downwash model is taken from actuator disk theory for a propeller, while the strength of the vortex pair is found by assuming a rectangularly loaded rotor blade [illegible] distribution. The partitioning is done by an exponential function. F rises from 0 at hover (the wake is all helicopter downwash) and quickly increases to a value toward 1 (the wake is all vortex pair). A model constant in F was set by comparison with preliminary free wake forward flight wake predictions (Hess et al., Ref. 12).

The simplified AGNESP model for the strength of the tip vortex circulation strength may be compared with predictions from the most detailed and advanced helicopter wake flow field model (Quackenbush and Bliss, Ref. 13). This work utilizes a numerical analysis based on the curved vortex element described in [illegible] (Ref. 17). The model is composed of vortex filaments laid down along the individual rotor blades through the wake. The skewed curved filaments provide a natural representation of the free wake vorticity fields, which [illegible] accurately accounts for both blade [illegible] and vorticity. An additional advantage of the [illegible] is that it provides a visually appealing representation of the wake since the filaments correspond to the actual resultant vorticity field. Vortex filaments leaving the blades are of constant strength and equal value. For this reason, close spacing between the filaments implies a strong net influence from this region of the wake, whereas a [illegible] indicates a region having little effect.

[illegible] the comparison [illegible] in the Ref. 13 [illegible] Figure 3-1 shows the vortex filament [illegible]. It is quite complicated and, when [illegible] the wake [illegible] field [illegible] [illegible] individually [illegible] [illegible] respectively, compared against AGNESP [illegible] The [illegible] [illegible] (1) [illegible] Th [illegible] [illegible] At [illegible] downward.

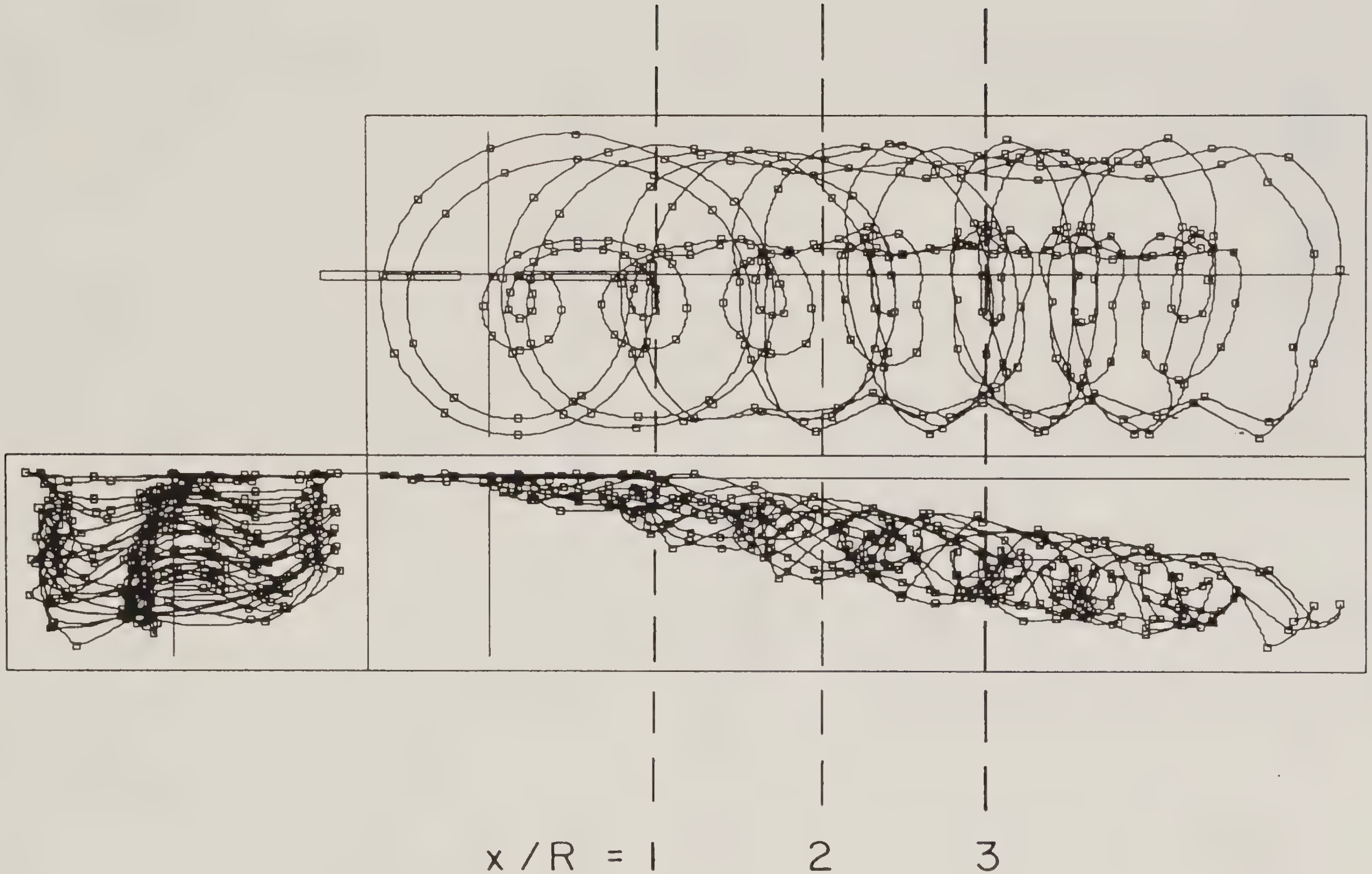


Figure 3-1: Helicopter wake flow field predictions using a detailed free wake computer model (Quackenbush and Bliss, Ref. 13): three views of the vortex filament structure off one blade.

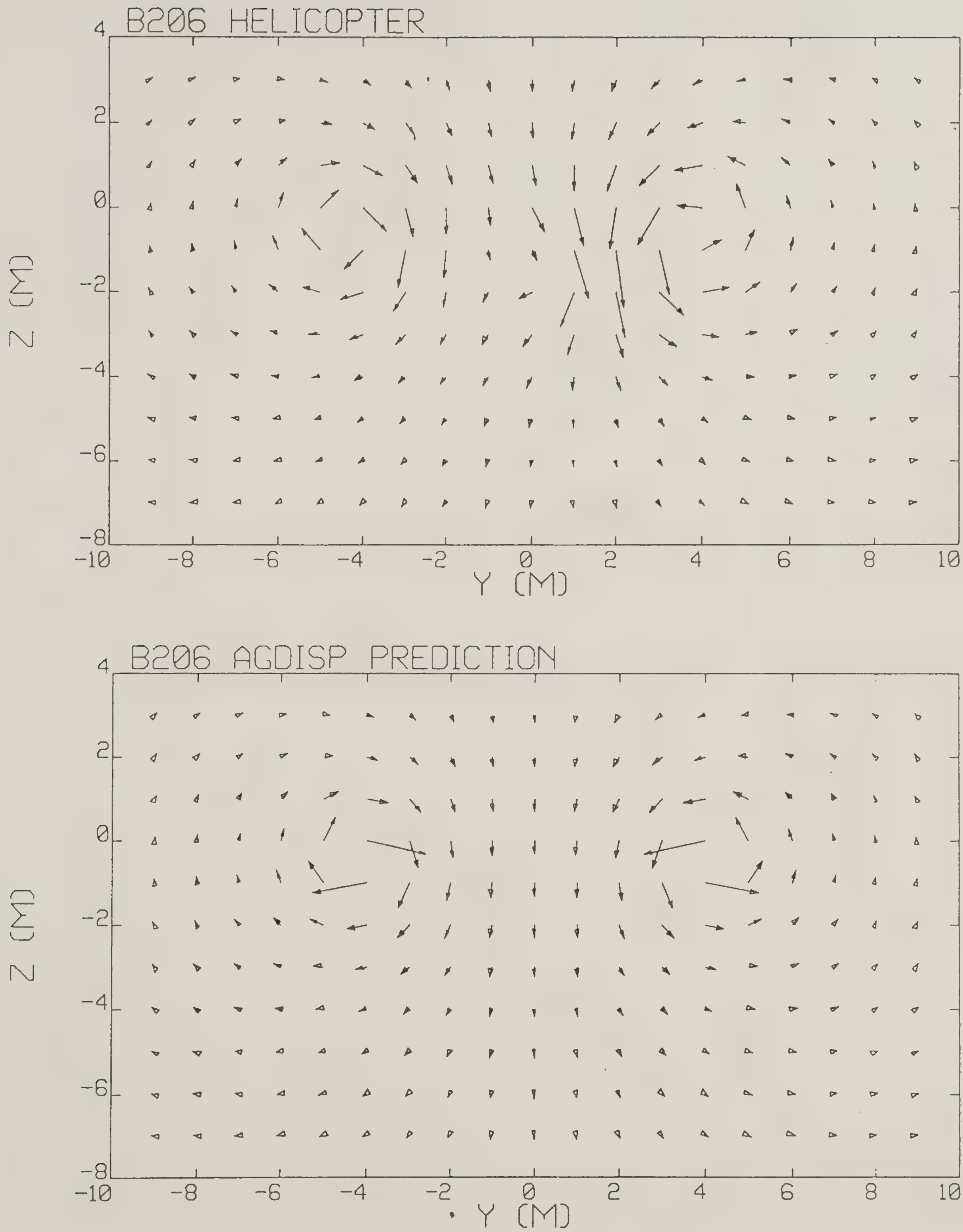
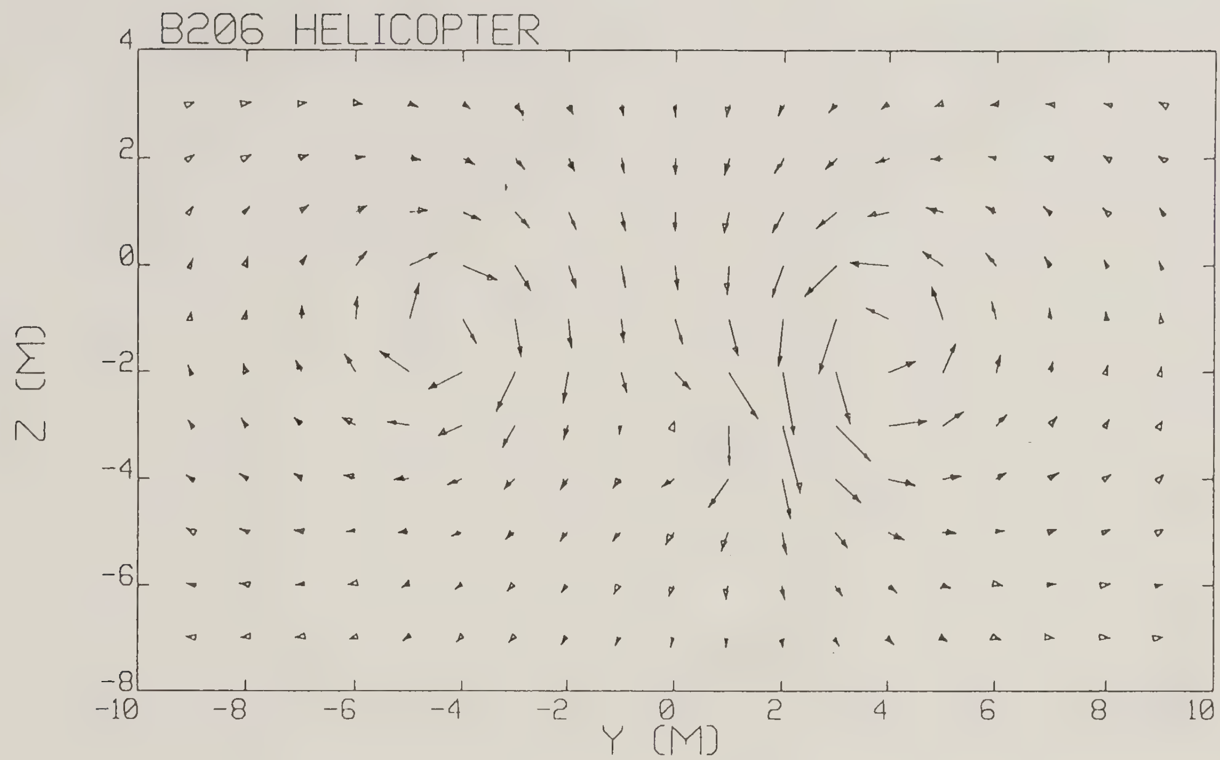


Figure 3-2a: Crossplane velocity vectors at a downstream distance of one radius (top) compared with AGDISP predictions (bottom).



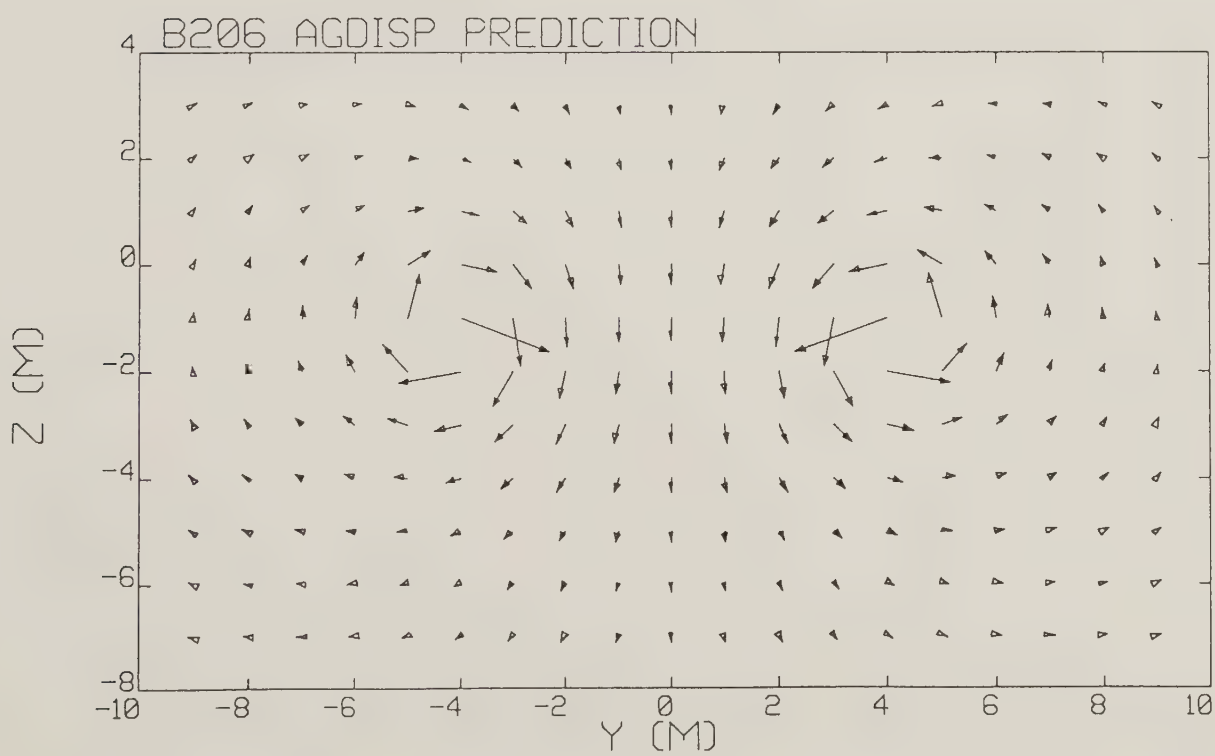
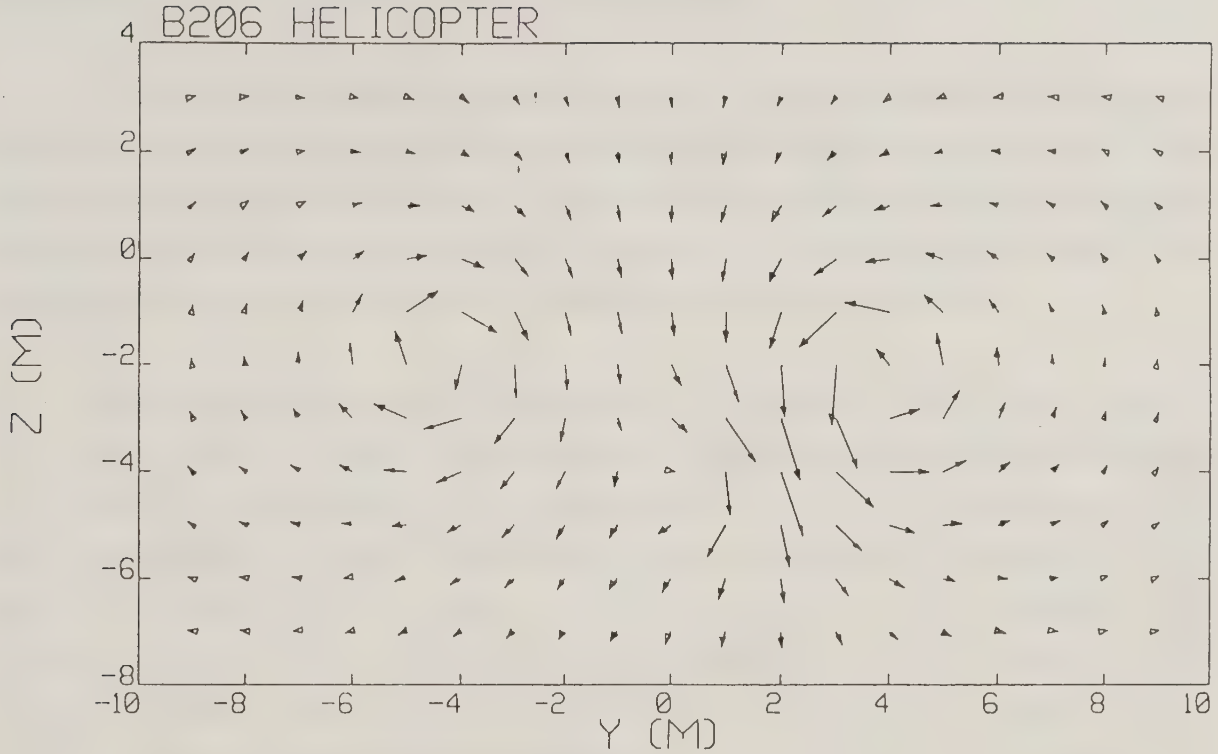


Figure 3-2b: Crossplane velocity vectors at two radii downstream.



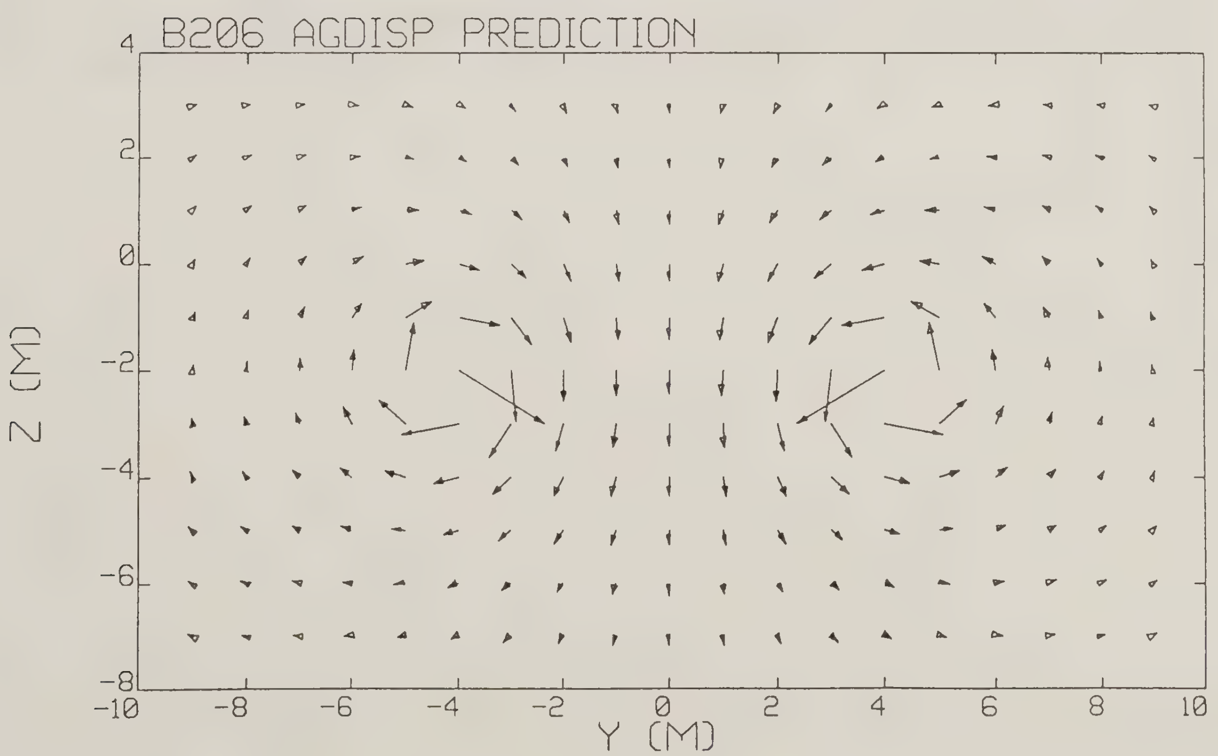


Figure 3-2c: Crossplane velocity vectors at three radii downstream.

The complicated helicopter model calculation took six hours on a MicroVAX II computer; a typical AGDISP run takes one to two minutes.

To reproduce the size of the velocity vectors in the complicated helicopter model required the imposition of a cutoff distance in the AGDISP helicopter model of 0.1R. This minor revision to the AGDISP model will reduce slightly the influence of the vortex when a droplet is very close to a vortical center. Further out, there will be no change in the influence of the vortex on the motion of material droplets in the simulation.

Recent anemometer tower data reduction for Program WIND Phases I and III (Bilanin et al., Ref. 14) lead to the refinement of a least squares influence coefficient technique for recovering the position and strength of the vortex pair generating the anemometer signals. This effort was directed toward discerning the decay rate of vortex pairs in the atmosphere, but the same technique can be just as easily applied to the crossplane velocity vectors shown in Figure 3-2 to recover their position and tip vortex circulation strength. The growth of this circulation strength may then be compared with the AGDISP model, giving the surprisingly good result shown in Figure 3-3. The exponential wake model in AGDISP does a remarkably good job of simulating the complicated wake flow field generated by the far more detailed helicopter code.

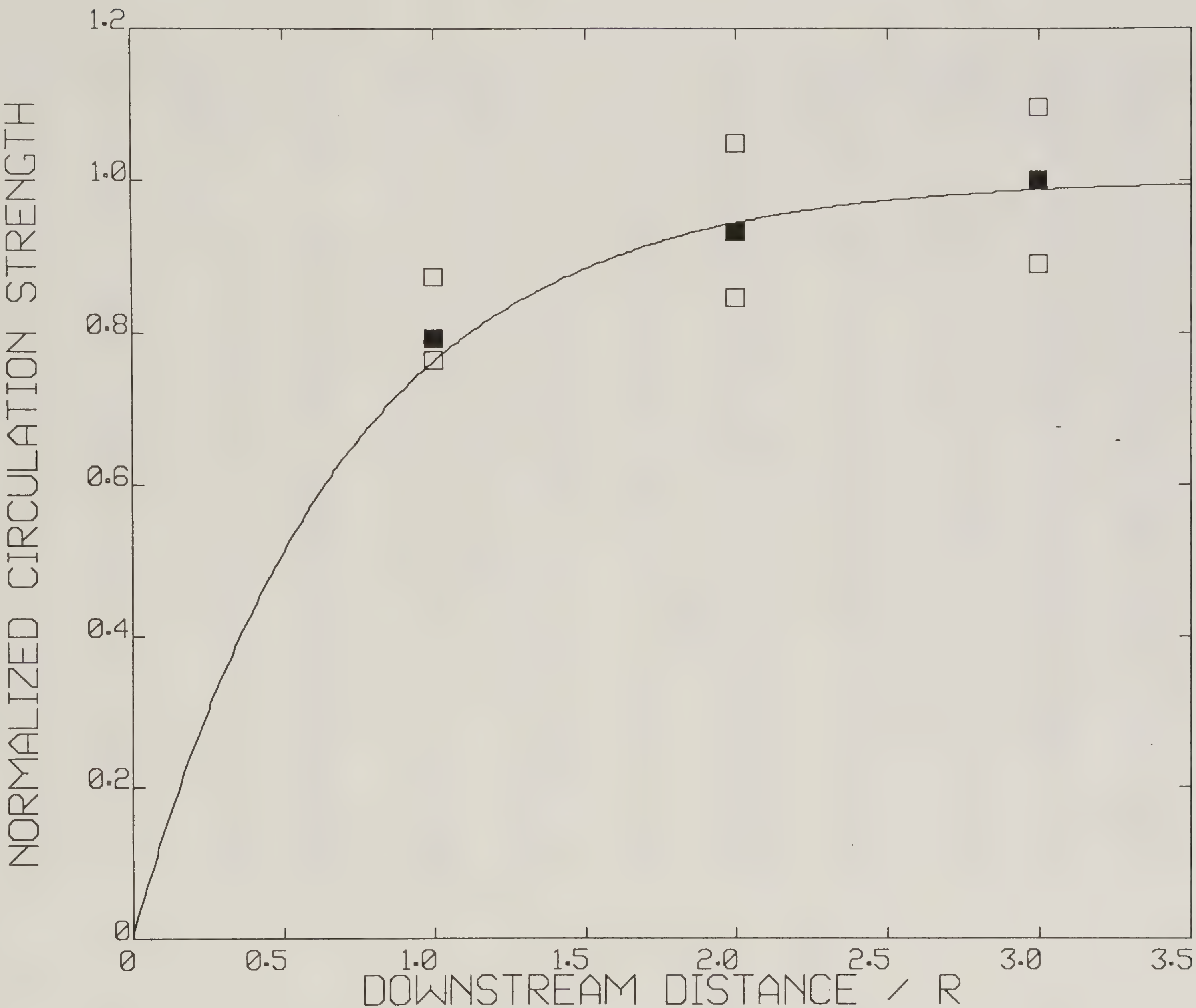


Figure 3-3: Comparison of the simplified AGDISP helicopter circulation model (solid curve) with data points (squares) inferred from a detailed free wake computer model (Quackenbush and Bliss, Ref. 13): open squares -- left vortex alone (top) and right vortex alone (bottom); closed squares -- composite.

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